SUSTAINABILITY OF STEEP LAND BEAN (PHASEOLUS VULGARIS L.) FARMING IN COSTA RICA: AN AGRONOMIC AND SOCIO-ECONOMIC ASSESSMENT

By

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DEDICATION

This work is dedicated to those who taught me what sustainability means:

Teeboy, Lito, and Jopy, who killed and died trying to liberate the oppressed Filipino peasant farmers.

The South-East Asian Social Rural Leadership Institute class of 1988, who put a human face on sustainability.

Amor, Ramiro and other farmer innovators, whose contributions to agricultural technology development are too often ignored.

The children of Costa Rica's small-scale farmers, whose future depends on sustainable agricultural development.

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KEY TO ABBREVIATIONS

BNCR.	National Bank of Costa Rica
CATIE	Center for Tropical Agricultural Investigation and Teaching
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Center for the Improvement of Maize and Wheat
CNP	National Production Council
FSR/E	Farming Systems Research and Extension
HYV	High Yielding Varieties
ICRAF	International Centre for Research in Agroforestry
IICA	International Institute for Agricultural Cooperation
LDC	Lesser Developed Countries
MAG	Ministry of Agriculture
MIDEPLAN.	Ministry of Planning
ONS	National Seed Office
UCR	University of Costa Rica
USAID	United States Agency for International Development

Abstract of Dissertation Presented to the Graduate School
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Changes in bean-production practices by farmers cultivating steep lands in Costa Rica have impacted on agroecosystem sustainability. *Frijol espeque*, an input-based, land-use intensive, dibble-stick-planted, bean-growing method, was introduced to replace *frijol tapado*, a broadcast-planted, traditional, low-labor, shifting agricultural practice. Socioeconomic impacts of the transition were assessed based on farmer surveys. Agronomic impacts of the transition were determined using on-farm experiments.

Frijol espeque produced significantly higher yields but lower returns on investment compared to frijol tapado. Clear-field and burned-field land preparation practices, used in frijol espeque, resulted in soil degradation as indicated by significantly greater soil losses due to erosion, depletion of plant nutrients, and increased soil bulk

density. Soil erosion was controlled, aggregate stability maintained, and plant nutrients conserved in the mulch-based frijol tapado system.

Frijol espeque and frijol tapado were compared with *labranza cero*, an intermediary bean production method. Labranza cero is planted in straight rows using a dibble-stick, similar to frijol espeque, but has cut, fallow growth retained on the soil surface as a mulch, similar to frijol tapado. Labranza cero produced similar yields to clear-field frijol espeque while controlling soil degradation to an extent similar to frijol tapado.

Farmers have decreased the use of fallow rotations due to land-use competition. Increasing land-use intensity resulted in significantly decreased phosphorus availability, increased erosion, increased weed and web blight infestation, and decreased yields. For labranza cero, crop residues alone provided an insufficient mulch layer to decrease soil erosion losses, weed regrowth, or web blight infestation. Use of a grass fallow, in combination with mulch-based frijol espeque, controlled soil erosion and increased the availability of nitrogen and phosphorus for plant uptake.

Both agronomic and sociopolitical factors are responsible for the decreasing sustainability of bean production on steep lands in Costa Rica. Agricultural development programs need to address and assess the impacts of farmer adaptations of introduced technologies and changing land-use practices on agroecosystem sustainability and equity within the society. Assessment methods based on a combination of modified stability analyses and ANOVA were shown to be effective in evaluating both the productivity and the sustainability of the agroecosystem.

CHAPTER 1
THE EFFECT OF TECHNOLOGY CHANGE ON THE SUSTAINABILITY OF BEAN PRODUCTION IN COSTA RICA

Sustainability

Sustainability: The Concept

Agricultural sustainability is a concept that encompasses the interaction among agriculture, household economics, the environment, society, and agricultural policies. As a result of the complexity and the temporal aspect of this concept, definitions of sustainability are often vague or contradictory. Many agricultural researchers and development workers, frustrated in their attempts to define the concept, simply state that agricultural sustainability is "understood intuitively."

Practically, sustainable agriculture is used to describe agricultural production or development activities that can be adopted easily by small-scale farmers. From the agroecosystem perspective, sustainable agriculture encompasses practices that have a minimal negative impact on the environment, rely predominantly on nutrient cycling and green manures for the maintenance of soil fertility, and promote systems diversity for pest and disease control. From the perspective of production, sustainable agriculture balances increased yields against risk investment rather than trying to obtain maximum yields. Agroforestry, multiple cropping, and mixed crop-livestock systems are considered more sustainable than monocropping and sole cropping systems. The latter are

regarded as agronomically more fragile and economically riskier. From the perspective of equitability, proponents of sustainable agriculture argue that sustainable agricultural production by resource-poor farmers today, and by their children tomorrow, can exist only if issues of land tenure, birth control, social security, economic development, and natural resource exploitation are addressed.

Conway (1985) defined agroecosystem sustainability as "the ability of the system to maintain productivity in spite of a major disturbance such as caused by intensive stress or a large perturbation." In his analysis, sustainability is but one of four properties of the social value of an agroecosystem. Besides sustainability, the other properties are: productivity, the measurement of production; stability, the coefficient of variation of productivity; and equitability, how production is shared. Although some agroecosystems exhibit high levels of all four properties, Conway (1991) argues that, in other situations, sustainability may need to be sacrificed to obtain higher levels of productivity or equitability.

In their definition of sustainability, the Technical Advisory Committee of the Consultative Group on International Agricultural Research (CGIAR) attempted to integrate economic growth and productivity with sustainable land-use practices. They stated that sustainable agriculture "should involve the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" (CIMMYT, 1989). According to this definition, sustainable systems may be difficult to implement. Although sustainable

systems are more productive in the long term, they may be less economically viable in the short run (Barbier, 1989).

Sustainability also has been defined in terms suitable for formulating development policies. The World Commission on Environment and Development (1987) report, also known as The Brundtland Report, defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." A member of the Brundtland Commission indicated that achieving sustainable development requires a change in government policies and expenditures (MacNeill, 1989). Policies should favor programs designed to protect crop-lands, slow or reverse deforestation, slow population growth, increase energy-use efficiency, develop renewable resources, and decrease the debt burden on developing countries.

The Implementation of Sustainable Agricultural Programs

Interest in agricultural sustainability arose in response to what were perceived to be unsustainable agricultural practices. In the United States, rising costs of fertilizer inputs and heightened awareness of adverse effects of pesticides on non-target organisms (Carson, 1964) resulted in a renewed interest in the use of green manures, multiple cropping, and integrated pest control (USDA, 1980). In lesser developed countries (LDCs), interest in sustainable agriculture arose in response to what was perceived to be the unsustainability and inequity of the "green revolution" (George, 1977; Lappé and Collins, 1978).

The green revolution centered on the development and distribution of seeds of maize, wheat, and rice exhibiting high yield response to agrochemical and labor inputs. The introduction of these high yielding varieties (HYVs) significantly increased the worldwide production of basic food grains and transformed several nations from importers to exporters (Brown, 1970). On the farm level, however, marginal farmlands, inability to afford inputs, low access to credit and markets, and insecure or usurious tenure agreements hindered adoption of the green-revolution technologies by many farmers (Roling et al., 1976; Fliegel, 1984). As a result, the impact of the green revolution was to accentuate differences in the production capacities of rich and poor farmers. Farmers with access to better land and agrochemical inputs could realize the higher yield potential offered by green-revolution varieties. Resource-poor farmers working marginal land and unable to apply fertilizers and pesticides were unable to realize the higher yields of these input-dependent varieties.

To include in the development process those small-scale or resource-poor farmers, who were unable to adopt the technologies of the green revolution, farming systems research and extension (FSR/E) programs were developed. In contrast to traditional transfer-of-technology extension methods, criticized as being researcher-driven and commodity-oriented, the farming system approach was designed to be interdisciplinary, whole-farm oriented, and based on farmer involvement (Shaner et al., 1982). Farming system development is initiated by conducting informal surveys or *sondeos* with farmers to determine their perceived needs and constraints (Hildebrand, 1981). A broad analysis of the farming system is conducted prior to conducting

experiments designed to satisfy the needs or alleviate the constraints expressed during surveys. In this process, problems are identified and prioritized. The causes, both environmental and socioeconomic, of the higher-priority problems are identified as are potential solutions (Tripp and Woolley, 1989). Testing of the potential solutions is conducted in conjunction with participating farmers under their constrained conditions. Experiments are conducted on farmers' fields, often utilizing farmer labor and management, rather than on experiment stations. By testing new technologies within the variable environment of the farmers' fields rather than within the optimal environment of the experiment station, appropriate recommendation domains for the technologies can be identified (Harrington and Tripp, 1984; Chambers and Ghildyal, 1985). Farmers are also involved in the evaluation process. As Rhoades and Booth (1982) noted, farmers may not adopt recommended practices for reasons that may appear illogical to the researcher but which are logical within the context of the culture or socioeconomic environment of the farmer. Alternatively, farmers may not adopt an innovation completely. Instead, they may conduct their own adaptive experiments until they have developed a creative integration of the technology with their own traditional methods.

Proponents of the "farmer-first" development paradigm criticize the original FSR/E methods as involving farmers but not being farmer-driven. Instead of incorporating farmers' opinions into researcher-designed development programs, farmer-first developers seek to involve farmers, both men and women, in their own development (Chambers and Jiggins, 1987a; 1987b). Designed specifically for resource-poor farmers, this approach does not seek to replace traditional agricultural practices but

instead to use these practices as a basis for the development of new technologies (Roling and Engel, 1989; Thrupp, 1989).

Agroecological Sustainability

The policies of the green revolution, criticized as being non-egalitarian and not conducive to sustainable program implementation, were also condemned as being environmentally degrading. The wide-spread adoption of HYVs resulted in a drastic loss of native germplasm (Cleveland and Soleri, 1989). Uncontrolled use of pesticides, many of which are banned in the industrialized countries due to high toxicity against non-target organisms, has caused pollution and health problems in LDCs. Soil degradation has occurred when farmers adopted land-use intensive farming practices but were financially unable to use fertilizers to replace nutrients which were removed due to land clearing and harvest. Erosion has resulted when technologies developed for level lands are inappropriately practiced on steeply sloping lands (Eckholm, 1976; Lal, 1984a).

Traditional agricultural systems use fallows and mixed agricultural systems to maintain soil fertility and to inhibit pest and disease infestations. Agroecologically, the sustainability of these practices is based on nutrient recycling and system diversity. When farmers replace traditional rotational systems with input-based systems, they substitute chemical fertilizers and pesticides for the biological control mechanisms provided by fallows and mixed cropping systems. In this process, the basis for system sustainability shifts from environmental to economic. The resilience of the system is no longer buffered by recycling processes combined with parasitic and mutualistic

interactions between system components. Instead, it is buffered by the ability of the farmer to obtain the cash required for inputs.

The paradigm of agroecology was developed to study and develop low-input management systems appropriate for use by resource-poor farmers. Agroecology recommendations are designed to increase diversity among and within the enterprises of the farm. System diversity enhances efficiency of nutrient recycling, moderates pest and disease infestations, and increases efficiency in the use of moisture, sunlight, and nutrients (Altieri, 1989).

To better assess the effects of introduced technology on the farming community, proponents of agroecology subdivide the community into various sectors (de Janvry and Helfand, 1990). Resource-poor farmers are considered members of subfamily farms. Subfamily farms are farming households with resource bases insufficient to economically support or to absorb the labor of the household. Involvement of one or more family members in off-farm labor activities is required to supplement the income derived from farming activities. Due to the reliance of this sector on crops and farming practices not addressed by the green revolution, technology introductions have not increased the on-farm contributions to the income of the subfamily farm. As a result of the marginalization of the subfamily farm due to the introduction of input-based technologies, the family becomes more dependent on off-farm sources of income.

In an attempt to assist the subfamily farming household to become more economically competitive, Altieri (1989) recommended the formation of integrated, community-based development programs aimed at conserving and efficiently using local

resources, minimizing dependency on external inputs, increasing the diversity of agricultural practices in order to minimize risks, improving the nutritional intake of the farm family, and ensuring that program benefits are equitably distributed among community members. The low resource base of subfamily farms, however, may restrict this sector from becoming economically competitive despite farmer-directed development policies. To generate higher monetary incomes for this sector, de Janvry and Helfand (1990) stressed that policies promoting land reform and economic opportunities in the rural areas need to be pursued.

Sustainability, Induced Technology Change, and Bean Farming in Costa Rica

Recently, programs of agricultural development organizations have exhibited increasing sensitivity to the concepts of sustainability. Many have incorporated the development of sustainable agricultural practices into their mandates. As the transition is made from researcher-directed to farmer-directed agricultural development, development organizations are increasingly interested in comparing the impact of their previous and current projects on issues of sustainability. Specifically, these organizations are interested in assessing the trade-offs made between productivity, sustainability, and short-term economic gains. For example, Torres (1991) asked, if productivity is given priority over sustainability, what levels of stress can be resisted by the system before sustainability is sacrificed?

The International Center for Tropical Agriculture (CIAT) has been involved, since 1973, in research designed to increase the production of beans (Phaseolus vulgaris L.) in Central and South America and the Caribbean. This work has included the

development of "genetically superior" cultivars of beans, examinations of cropping systems, and studies on nitrogen fixation (CIAT, 1987; 1988a). In 1989, CIAT requested a study in Costa Rica directed at assessing differences in the sustainability of traditional, compared to introduced, bean production practices.

In Costa Rica, the common bean is an important component of the daily diet and a primary ingredient in several traditional dishes. The annual per capita consumption of beans is 10-13 kg, which provides approximately 10% of the dietary protein (van Schoonhoven and Voysest, 1989). For resource-poor farmers who grow the majority of Costa Rica's beans, bean production is both a source of income and of protein.

The traditional method of bean production in this country is the pre-Hispanic practice of *frijol tapado* or covered beans (Patiño, 1965). Frijol tapado is a broadcast-planted, land-use extensive practice formerly used throughout the monsoonal Pacific Coast zone extending from Costa Rica to Ecuador. Slash-and-mulch farming practices similar to frijol tapado are currently used in Costa Rica, Ecuador, Colombia, Peru, and Brazil (H.D. Thurston, personal communication). This practice uses no commercial inputs and requires low labor inputs.

To allow farmers to adapt to changes in relative resource scarcities, a multi-institutional program was created in 1978 to research, evaluate, certify, and distribute new varieties of bean seeds (Pachico and Borbón, 1987a). The institutions involved in this effort were the Ministry of Agriculture (MAG), the University of Costa Rica (UCR), the National Production Council (CNP), the National Seed Office (ONS), and CIAT. The coordinated efforts of these organizations resulted in the release of the

erect, determinant bush, or Type I black bean variety, Talamanca, in 1981 (Figure 1.1). In 1982, a spreading, indeterminate bush, or Type II bean variety, Brunca, was released for farmer use. These varieties were introduced to replace traditional seed varieties characterized as Type III (indeterminate prostrate) and Type IV (indeterminate climbing).

In conjunction with adoption of these bean varieties, farmers began adopting the *frijol espeque* planting method. Frijol espeque is characterized by planting beans in straight rows using a dibble-stick or *espeque*. By planting their beans in straight rows rather than by broadcasting, farmers are able to more easily control diseases and insects using pesticides, and to manage soil fertility using fertilizers (Pachico and Borbón, 1987a). The combination of the new planting method, introduced seed varieties, use of commercial inputs, and increased labor inputs for weed control makes frijol espeque more input-intensive than frijol tapado. The yield potential for frijol espeque is also higher than that for frijol tapado. Based on farmer surveys, Pachico and Borbón (1986) reported average yields of 569 kg ha^{-1} for frijol tapado planted with traditional varieties, compared to yields of 941 kg ha^{-1} for frijol espeque using introduced varieties.

The use of agrochemicals in frijol espeque allows farmers to use their land more intensively. Despite the potentially higher yields of frijol espeque, frijol tapado can provide almost three times the returns on capital investments compared to frijol espeque (income/cost=10.60 for tapado versus 3.76 for espeque) when the opportunity value for land is low (CIAT, 1988a). A high, competitive, opportunity value for labor during the period of bean growth also favors frijol tapado over frijol espeque. No labor inputs are

used for frijol tapado during the period between planting and harvesting. It is, therefore, favored in areas where off-farm activities, particularly coffee harvests, provide farmers with a secure source of income during the period of bean growth (-Ballestero, 1985).

Frijol tapado is planted on land that has been fallowed for 9 months to 5 years (M. Amador, personal communication). This fallow period is used to regenerate soil fertility and provide biological control of pests and diseases. In contrast, the adoption of frijol espeque allows farmers to continuously crop a bean-maize rotation within a single year.

Many resource-poor farmers have adopted the fundamentals of the frijol espeque technology. Their lack of economic resources, however, often makes them unable to apply the recommended rates of fertilizers and pesticides. Many farmers also plant frijol espeque on highly erodible, steeply sloping lands. Although frijol espeque can produce significantly higher yields than frijol tapado, a decrease in the sustainability of bean production may occur concurrently with the transition from frijol tapado to frijol espeque.

The productivity of the frijol tapado system has also declined. Where land-use pressure forces farmers to plant frijol tapado on land fallowed for less than 2 to 3 years, this rotational agroforestry practice has been transformed into a crop-fallow or "agro-shrubbery" system. The use of only minimal labor inputs and no chemical inputs in frijol tapado results in a decrease in the productivity of the system as fallow length decreases.

Frijol espeque has been the focus of a major technology transfer and research program. Recommended practices for this system have been described in research reports (Corella, 1989; Hugo, 1989; Tapia et al., 1989) and in extension pamphlets (Trece et al., 1989; CNP, 1990). Information regarding frijol tapado is much more limited. On-farm assessments of frijol espeque or comparisons between frijol espeque and frijol tapado have been limited to socioeconomic studies (Solano, 1980; Chapman et al., 1983; Barrantes et al., 1986; Pachico and Borbón, 1986). Some studies also contain data that is confounded (Ospina, 1990) or incompletely described or justified (Shenk et al., 1979; von Platen and Rodríguez, 1982). Due to the scarcity of agronomic research information on frijol tapado or on farmer implementation of frijol espeque, a review of the literature leaves as many questions unanswered as it answers.

Bean Farming Methods in Costa Rica

Introduction

Bean production in Costa Rica is concentrated within the Central Mesa and in the half of the country bordering on the Pacific Coast. Within this area, there are four principal bean growing regions: the northern zone including Upala and Los Chiles, the Nicoya Peninsula within the province of Guanacaste, the Central Mesa around San Jose, and the southern zone from San Isidro de General to Buenos Aires (Figure 1.2). In the northern zone, beans are grown on relatively level land by large-scale commercial operators. In contrast, on the undulating to steeply sloping lands of the Nicoya

Peninsula, the Central Mesa, and the southern zone, bean production is primarily the work of small holders.

In 1950, most beans grown in the El General Valley in the southern zone of Costa Rica were grown using frijol tapado (Skutch, 1950). Between 1980 and 1987 the percentage of land in bean production planted using frijol tapado decreased while the percentage of land used for frijol espeque increased. In 1980, 80% of the land was planted using frijol tapado, while frijol espeque was planted on only 18% of the land. During the 1986-87 production season, the percentage of land planted to frijol tapado had decreased to 49%, while frijol espeque was practiced on 38% of the land (CIAT, 1988a). One-third of the farmers interviewed by Borbón (1984) in the San Isidro area said they had converted from frijol tapado to frijol espeque during the ten-year period from 1973 to 1983.

Frijol tapado is currently practiced within the regions of Upala, Guanacaste, Acosta, San Isidro, and Coto Brus. These regions, located along the Pacific Coast, all have steeply sloping lands and a monsoonal climate.

Frijol Tapado

Frijol tapado is a rotational agroforestry practice. Traditionally, and under conditions of low land-use competition, a farm is divided into 3 or 4 lots. Each year, frijol tapado is planted on one lot while the other lots remain in fallow. Woody species, typical of the early stages of forest succession, dominate 3- to 4-year fallows used for frijol tapado production. When land-use competition is high, frijol tapado is practiced

on the same lot each year. Pasture grasses, plantains, herbaceous plants, and ferns dominate the short, 9 month fallows used for annual production of frijol tapado.

Frijol tapado planting method. To plant frijol tapado, a farmer initially cuts narrow pathways through the fallow growth, following the contour of the land. The distance between pathways depends on the slope of the land, the height and thickness of the fallow growth, and farmer preference. Typically, a farmer cuts pathways 6-8 meters apart. From within these pathways, the farmer broadcasts bean seeds into the standing fallow growth between the pathways. From the lower pathway, seeds are broadcast upward into the lower half of the intervening standing fallow. Then, moving to the next higher pathway, the farmer broadcasts seeds downward into the upper half of the intervening area. Alternatively, the farmer cuts pathways 3-4 meters apart and broadcasts seeds into the entire intervening area from the pathway below the area to be planted (Figure 1.3a).

After the seeds are broadcast, the farmer cuts the remaining fallow growth with a long machete (60-70 cm long). The cut residues cover the bean seeds. The height to which the fallow is chopped depends on the growth habit of the beans. When erect, less aggressive varieties are planted, weeds are cut close to the ground. When more aggressive, climbing bean varieties are planted, tree trunks are left standing as trellises (Araya and González, 1987). Farmers prefer aggressive, indeterminate, Type III and Type IV varieties of beans for frijol tapado production. These varieties are highly competitive with weeds, since they can climb or grow over the regenerating fallow growth.

The emergence of the germinated beans from beneath the mulch layer is facilitated by coarsely chopping the cut fallow with a machete (Figure 1.3b). To further offset the low emergence rate characteristic of this planting system and to make the beans more competitive with weeds, sowing rates of 35-50 kg ha^{-1} are recommended. This is one and one-half to two times the sowing rate recommended for frijol espeque (CNP, 1990).

Soil fertility maintenance and pest control for frijol tapado. Following the planting of a tapado bean field, the beans normally grow without any additional management or labor inputs until harvest. Neither fertilizers nor pesticides are typically applied to frijol tapado fields.

Natural fallows are used instead of commercial inputs to regenerate soil fertility and decrease infestations by pests and diseases. In addition, nutrient recycling is enhanced and weed regrowth may be reduced by maintaining crop residues on the soil. This mulch cover also may protect the soil against nutrient losses due to erosion, caused by the impact of intense tropical rainstorms. Galindo et al. (1983) reported lower incidence of a splash-dispersed fungal disease, web blight [Rhizoctonia solanii, Kuhn, anomer Thanatephorus sucumeris (Frank) Donk], in frijol tapado fields compared to clean-fallowed fields.

Under conditions of 1-2 year, grassy fallows, lack of herbicide application and mid-season manual weeding may allow weeds to regrow during the growing season and compete with the beans for nutrients, water, and sunlight. Weed regrowth also may

serve as a source of inoculant or as an alternative food source for diseases and pests of beans.

Socioeconomic factors affecting frijol tapado. Frijol tapado is a low-input, low-risk production system. It is used predominantly by farmers who have low access to economic resources or who live in areas with low accessibility to markets. Frijol tapado is also favored in areas where other on-farm or off-farm activities provide a high opportunity value for labor during the period of bean growth (Ballestero, 1985). In the coffee-growing area around San Vito, bean production activities occur simultaneously with the highly profitable coffee harvest. By substituting the decreased weed growth and disease incidence provided by fallows for labor inputs, farmers can obtain bean yields per hectare close to those obtained using frijol espeque while being able to engage in the coffee harvests.

The profitability of frijol tapado is dependent on a low opportunity value for land use. Pachico and Borbón (1986) reported that, of the farmers interviewed who owned less than 50 hectares of land, less than one-half felt able to leave a portion of their land in fallow. For farmers owning 10 hectares or less of land, only 16% were able to maintain a fallow rotation. Farmers with small land holdings or with land accessible to major transportation arteries use their land for the production of frijol espeque or other high-value crops, such as coffee or vegetables. If they desire to plant frijol tapado, they do so as tenants. Frijol tapado is planted on parcels of land that are more mountainous, less accessible, and less valuable than lands used for more commercial crops.

Due to the availability of preferential loans for cattle production during the 1980s (Annis, 1987) and the expansion of coffee production into San Isidro and Coto Brus (Chapman et al., 1983), the availability of land to tenants for frijol tapado production decreased. This resulted in the duration of fallow periods between croppings being decreased. The option of small-scale farmer landholders to plant frijol tapado has also decreased.

Frijol tapado research. Despite the social and economic importance of frijol tapado in Costa Rica, few investigations have been conducted on this system. Reasons for the lack of scientific interest include the belief that tapado bean production is not responsive to inputs or improved management practices, and the reality that it is practiced in areas with low accessibility to extension agents (Araya and González, 1987). Additionally, the major economic advantages of frijol tapado are the minimal labor and cash inputs required. Thus, the introduction of technologies to increase frijol tapado yields through intensified management of the system may not be acceptable to farmers.

Researchers who have investigated frijol tapado suggest that nominal management modifications could increase yields per hectare while retaining most of the advantages of this system. Von Platen and Rodríguez (1982) obtained a 22% increase in frijol tapado yields when 150 kg ha^{-1} of 10-30-10 NPK fertilizer and pesticides (500 g ha^{-1} Orthene 95% to control Diabrotica sp. and Aldrin 25% to control slugs) were applied by broadcasting. Rosemeyer (1990) reported a significant increase in frijol tapado yields when nitrogen and phosphorus fertilizers, at rates up to 35.1 kg ha^{-1} of N and 97.5 kg ha^{-1} of P, were broadcast-applied. Neither Rosemeyer (1990) nor Araya and González

(1987) obtained significant increases in yields per hectare due to rhizobium inoculation of frijol tapado-planted traditional bean varieties.

Shenk et al. (1979) obtained an increase in yields from 77 kg ha^{-1} to 495 kg ha^{-1}, while increasing labor costs by only 16%, due to dibble-stick planting rather than broadcasting seeds. This indicates that bean emergence is more reliable when seeds are dibble-stick planted rather than broadcast. It also may be indicative of the ease of obtaining misleading results for frijol tapado. Araya and González (1987) indicated that the experience of the planter can significantly affect yields obtained from frijol tapado.

Frijol Espeque

Frijol espeque planting method. Frijol espeque is characterized by planting beans in straight rows using a dibble-stick (Figure 1.3c). Crop management activities are facilitated by planting beans in straight rows. In contrast to frijol tapado, frijol espeque employs commercial inputs and is less dependent on fallow periods to regenerate native fertility. Recommended frijol espeque methods include planting certified seeds, two applications of fertilizers, chemical or manual weed control during the first 30 days of bean growth, and applications of agrochemicals to control insects and fungal diseases (CNP, 1990). Unlike the majority of other Latin American countries, beans are grown in Costa Rica principally as a sole crop rather than as an intercrop with maize. By adopting frijol espeque, beans and maize can be grown as rotation crops on the same plot of land during the two growing seasons per year.

Use of fire in the preparation of frijol espeque fields. When practiced on steeply sloping lands or under conditions of low resource availability, frijol espeque is planted

without plowing. To facilitate production activities, minimize weed infestation, and control against pest and disease infestations, the land is normally cleared before planting. According to a farming systems study conducted by MAG personnel in an area near Pejibaye de Pérez Zeledón during the 1985 growing season, 74% of the farmers used fire to clear their land in preparation for the bean planting season (Barrantes et al., 1986). Alternatively, fields are cleared by grazing cattle on the fields during the dry season or by piling cut fallow residues on the edges of the field.

A majority of the farmers interviewed by Barrantes et al. (1986) stated that they burned their fields in an attempt to reduce slug (Vaginulus plebeius) damage. Slugs were accidentally introduced into Central America in the early 1960s. Within ten years, slugs have become a major pest problem throughout the wet, Pacific coast, bean-growing region (Andrews, 1987). In central Honduras, one-half of the land devoted to bean growing in 1974 was abandoned by 1979 due to uncontrollable slug problems (Rodríguez, 1980). Slugs are nocturnal feeders which feed principally on young, succulent plants. During the day, these soft-bodied mollusks shelter beneath residues to avoid desiccation. Slugs can be controlled by using molluscacides (Andrews, 1985) or with manual capture methods (Sobrado and Andrews, 1985). The method recommended by MAG, however, as being most effective for slug control, is the removal of all residues from the surface of the soil (MAG, 1988).

Frijol espeque planting on steeply sloping lands. Most small-scale farmers plant beans on land having slopes of 50% to 70%. This is due to tradition, preference, and displacement. Farmers traditionally associate sloping lands with bean production, since

frijol tapado is usually planted on sloping lands. Sloping lands are preferred for bean production because, during periods of heavy rainfall, rainwater does not collect on the fields. This decreases the susceptibility of beans to web blight and other fungal diseases. Finally, for moderate to large-scale landowners, profits from cattle production can be obtained at a lower risk, with fewer labor inputs, and with greater access to credit than can profits from beans. The higher opportunity value for land in cattle production compared to beans has resulted in the placement of most level lands into cattle production.

The practice of clean cultivation on steeply sloping lands can encourage high rates of erosion. In an attempt to develop less erosive, intermediary, agricultural practices, MAG specialists are currently conducting studies on the use of mucuna (Mucuna utilis) as a cover crop and the planting of barrier rows of lemon grass (Cymbopogon citratus) along the contour lines. They are also encouraging farmers to leave residues on the soil surface during the growing season. This latter practice is called *labranza cero* (G. Ramiro, personal communication).

The Transition from Frijol Tapado to Frijol Espeque

Adoption of frijol espeque. The objective of the coordinated extension program has been to replace frijol tapado with frijol espeque. Since frijol tapado uses low labor inputs and has a low response to agrochemical inputs, most researchers and extension agents in Costa Rica treat this production method as a "primitive" system which should be eradicated (Rosemeyer, 1991).

In the area of Pejibaye de Pérez Zeledón, the transition from frijol tapado to frijol espeque was favored by an extension program that provided farmers with credit for the purchase of introduced seeds and agrochemical inputs (Chapman et al., 1983). This program also set the purchase price for beans by establishing buying stations during the harvest season. Access to inputs and markets was also increased by the construction, in the early 1980s, of an asphalt road between Pejibaye and the Inter-American Highway.

Although extension programs have been partially successful in increasing the adoption of frijol espeque, frijol tapado is still practiced by almost 50% of the bean farmers in Costa Rica. In the regions of Acosta and San Vito, frijol tapado accounts for over 90% of bean production (M. Amador, personal communication; Rosemeyer, 1991). Farmers may also use both practices, but on different parcels of land. Due to a continuous cover of vegetation or mulch over the soil surface, frijol tapado provides better control of web blight and soil losses due to erosion than does frijol espeque planted on bare fields. Therefore, farmers may choose to plant level or gently undulating lands to a frijol espeque / maize rotation, and to use their steeper lands for frijol tapado production (Pachico and Borbón, 1986; Monge et al., 1987).

The effect of frijol espeque adoption on the sustainability of bean production. When land is relatively abundant, frijol tapado is the more environmentally sustainable system. This is due to the regeneration of soil fertility and the stabilization of pest populations during fallow periods. During the growing season, the maintenance of a plant residue mulch over the soil surface decreases soil erosion and pest infestations. It

is also an economically sustainable system for resource-poor farmers. Due to its low labor and agrochemical input requirements, farmers can use frijol tapado to diversify their labor activities and minimize their economic risks.

As population pressure places increasing demands on land use, however, the changing resource situation reduces the relative advantages of frijol tapado. Economic and population pressures force farmers to use their land more intensively. This means using shorter fallow cycles and/or converting forest lands into bean production. Changing resource pressure also may persuade farmers to convert from frijol tapado to frijol espeque.

When practiced on moderately level lands with recommended rates of inputs, frijol espeque may produce stable production levels. When practiced on the steeply sloping lands traditionally used for frijol tapado, frijol espeque may be unsustainable due to loss of soil organic matter by erosion. When practiced by resource-poor farmers who are unable to afford agrochemical inputs, soil nutrients are depleted since nutrients removed through land clearing and harvest are not replaced through the use of fertilizers.

The literature indicates many significant differences between frijol tapado and frijol espeque production methods (Table 1.1). Many questions, however, are left unanswered regarding the adoption of frijol espeque and the relative sustainability of the two systems. Do agronomic or socioeconomic factors have primary influence over farmers' decisions to change bean production technologies? Why have farmers in some areas of Costa Rica adopted frijol espeque while in other areas farmers continue to use frijol tapado? Which planting method is most profitable and least risky for tenant

farmers? For farmers who use both planting methods, does adoption of introduced varieties for frijol espeque result in an adoption of these varieties for frijol tapado? Can frijol espeque be modified to produce a system which is both productive and sustainable?

The Assessment of Sustainability

Consequences of Degradation

Sustainability is often assessed by measuring its converse, non-sustainability or degradation. Consequences of agroecological degradation include: soil erosion, loss of soil organic matter, exhaustion of soil nutrients, desertification, deforestation, loss of genetic biodiversity, build-up of pest and disease infestations, environmental pollution, decreased yields, disruption of water supplies, reduced future availability of agricultural inputs, and global warming (Liverman et al., 1988; Jodha, 1990; Sims, 1990; Harrington, 1991). Aspects of socioeconomic degradation include overpopulation, a decreased standard of living, malnutrition, loss of control of the resources of production, and social unrest (Redclift, 1987; MacNeill, 1989).

Soil degradation is often cited as an important indicator of decreasing environmental sustainability (Brown, 1987; IUCN, 1980). Soil resources can be degraded chemically, physically, or biologically. Chemical soil degradation is indicated by decreases in soil organic matter and cation exchange capacity, depletion of plant-available nutrients, soil acidification, and aluminum toxicity (Logan, 1990). Examples of physical soil degradation include soil erosion, increased soil bulk density, and decreased water flow and infiltration (Hillel, 1982). Microbiological processes are

controlled by the availability of soil organic matter. Removal of organic substrates results in decreased diversity of the microbial community and disruption of nutrient cycles (Sims, 1990). Decreased soil organic matter and nutrients may also decrease the activity of microorganisms responsible for soil aggregation (Elliott, 1986).

Intensification of agricultural land use can accelerate the soil degradation processes. The replacement of forests by annual crops results in a considerable loss of nutrients (Nair, 1984). In a forest ecosystem, nutrients are immobilized in plant biomass. Removal of the biomass by burning enhances the availability of cations but also causes nutrient loss due to nitrogen volatilization and post-burn nutrient leaching (Ewel et al., 1981). Deforestation also can result in decreases in soil organic matter and increases in soil bulk density (Adejuwon and Ekanade, 1987). Reductions in fallow time allowed between successive croppings result in decreases in soil organic matter levels and in associated nutrient availability (Greenland and Nye, 1959).

The practice of bare-land farming practices on steeply sloping land promotes soil losses by erosion (Lal, 1984a). On soils having well-developed subsoils and no restrictions to rooting, crop productivity can be maintained if nutrients lost due to erosion are replaced by fertilizers. On shallow or poorly developed soils, erosion can cause irreversible soil degradation (Lal, 1985). Erosion-associated soil degradation causes depletion of soil organic matter, disruption of microbiological processes, increased bulk density, and depletion of plant-available nutrients.

Depletion of plant-available nutrients also results when nutrients are removed from the land due to land clearing and harvest. These nutrients may be restored through

fallowing or fertilization. Adopting continuous cropping practices without application of fertilizers results in a depletion of plant nutrients.

Parameters for Assessing Sustainability

The parameters used to describe degradation or loss of sustainability are dynamic. They exhibit spatial dimensions and are interactive with other factors in the environment. Furthermore, the definitions for economic, agricultural, and ecosystem sustainability are often contradictory (Redclift, 1987). The sustainability of ecosystems implies a balance between inputs and outputs while, from a development perspective, economic and agricultural sustainability implies growth. In addition, confusion exists regarding what time frame and discount rates to use when comparing traditional and input-intensive systems. The interactions, contradictions, and confusions associated with the concept of sustainability make its assessment difficult. Despite these difficulties, attempts have been made to develop criteria to assess sustainability, or its converse, degradation.

Criteria used for the assessment of sustainability must be both comprehensive and discrete. Senanayake (1991) views sustainability as maintaining a dynamic equilibrium between inflexible boundary conditions. Thus, determination of sustainability should consider boundary conditions and internal dynamics. These factors are measured in reference to ground states of absolute sustainability, or to thresholds where sustainable systems become irreversibly unsustainable. For example, Liverman et al. (1988) emphasized that rates of soil erosion are only indicative of sustainability if they are

expressed in terms of a rate-to-stock ratio, or the percentage of topsoil lost during a given period of time.

Conway (1991) suggests assessing agroecosystem sustainability according to five characteristic responses of a system to shock. These responses include inertia, elasticity, amplitude, hysteresis, and malleability. Inertia is the resistance of the system to change. Elasticity is a measure of the time required for productivity to recover following a disturbance. Amplitude is the maximum amount of shock or disturbance from which a system can recover. Hysteresis measures the rate of recovery. Malleability estimates differences in system steady states before and after a disturbance. These characteristics of sustainability may be used to assess both the absolute and relative sustainability of a system. They are also useful in differentiating between stability and sustainability.

For example, when land is brought into cultivation, the organic matter content of the soil decreases rapidly, then stabilizes. The organic matter content of the soil, thus, eventually could be characterized as stable, while the sustainability of the system could be characterized as highly malleable. Inability of the cultivated soil to recover an organic matter content characteristic of an undisturbed system indicates that the system is inelastic and has a low level of inertia and hysteresis.

Several approaches to measuring sustainability have been proposed. Harrington (1991) recommends using measurements that evaluate only the direction of change in system sustainability and not the magnitude of such change. He suggests that assessments of yield trends in relation to inputs applied may be acceptable if assessments also take into account technology changes and resource degradation. Senanayake (1991)

suggests evaluating sustainability using an index that accounts for changes in external inputs, energy ratios, power use, efficiency of solar flux use, erosion, and microbial biomass. Hildebrand and Ashraf (1989) proposed using a linear program to assess sustainability. Their linear matrix included an objective equation related to profit maximization. This was combined with equations accounting for the proportion of the land in fallow, and constraints related to the use of external chemical inputs.

Economic Measurements of Sustainability

In farming systems, agroecosystem sustainability and economic sustainability are closely interrelated. Agronomic and economic risk aversion is sought by maintaining a diversity of agricultural practices (Altieri, 1987). A transition from traditional to commercial input-based farming systems may provide the farmer with higher per hectare profits. The use of a commercial input-based system, however, requires farmers to have access to cash or credit in order to purchase inputs and pay for laborers. When the poor lose access to resources sufficient to fulfill their basic needs, often they are forced to sacrifice long-term sustainability of their farming practices to obtain short-term survival. The need to obtain cash to purchase inputs or to pay laborers may also result in resource-poor farmers becoming increasingly dependent on usurious money lenders.

The potential ethical changes that occur concurrently with the transition from traditional to commercial input-based agricultural systems require that economic comparisons be based on more than cash outlays and cash returns. Valuation must be based on the sacrifices the farm family makes to obtain cash for their farming

operations. Value must also be placed on the increased standard of living a more productive farming method may provide.

The current economic system places a low value on natural resources (Redclift, 1987). This, combined with the ability of agrochemical inputs to dominate the environment, allows farmers to profitably produce a low-value crop while simultaneously degrading soil resources. Since environmental resources are considered common-property goods, their economic valuation is unclear (Barbier, 1987; Manning, 1987). When low economic valuation is placed on natural resources, the extermination of species or the irreversible degradation of soils may appear economically justified (Tisdell, 1988). Consequently, the use of cost/benefit analysis to assess economic sustainability necessitates a careful selection of discount rates for resource use and a sensitive valuation of intangibles such as environmental or social benefits (Manning, 1987).

Assessing the Sustainability of Bean Growing Methods on Steeply Sloping Lands in Costa Rica

For small-scale farmers in Costa Rica, land use, input use, and bean-growing practices are in a period of transition. Different farmers use different lengths of fallow periods in their practice of frijol tapado. The number of frijol espeque and frijol maize rotations a farmer plants before placing the land in fallow once more varies. Frijol espeque land preparation practices also vary from bare-land to labranza cero. Thus, the sustainability of bean growing practices cannot be assessed simply by comparing traditional frijol tapado with introduced frijol espeque.

Assessments of sustainability must also account for differences in productivity and degradation process across environments. Land, labor, and input use employed within each system and among different environments must also be considered. In making economic comparisons among bean growing practices, the opportunity cost of land fallowed for frijol tapado must be calculated. In addition, the opportunity value for off-farm labor during the frijol tapado growing season must be estimated.

Although no comparisons have not yet been reported, it is supposed that soil loss due to erosion is lower with frijol tapado than with frijol espeque (von Platen and Rodríguez, 1982). Frijol espeque may be practiced without residues left on the soil surface or, as in labranza cero, with residues on the soil surfaces. Thus, comparisons of erosion losses and associated degradation processes should include labranza cero as well as frijol tapado and bare-field planted frijol espeque. Assessments of erosion-associated decreases in sustainability should include not only measurements of soil losses due to erosion, but also assessments of soil organic matter, microbial activity, and soil aggregate stability.

Pest and disease infestations are culturally controlled in frijol tapado by using mulches and fallows. Retention of crop residues over the soil surface decreases the incidence of web blight (Galindo et al., 1983). Weed infestations are suppressed following extended fallow (Ramakrishnan, 1988). In frijol espeque, weed and disease infestations are controlled by using pesticides. Sustainability of pest control requires both an assessment of infestation levels and a comparison of the direct and indirect costs associated with each system.

The conversion from long to short fallow frijol tapado or from frijol tapado to frijol espeque involves trade-offs between productivity and other agroecosystem properties: sustainability, stability, and equity (Table 1.2). Frijol tapado requires access to sufficient land to practice a fallow rotation. Alternatively, tenancy rights to fallowed land must be obtained and tenancy costs paid. Maintenance of system productivity in frijol espeque depends on the ability of the farmer to replace nutrients removed and to control pests and diseases. Input use, in turn, is affected by the access of farmers to resources and by the balance between input costs and prices paid for beans. Increasing system degradation may require farmers to apply increasing amounts of inputs and to receive decreasing returns on their cash and labor investments in order to obtain stable production levels.

Research Objectives

The research reported here was designed to assess the effect of technology change on the agroecosystem sustainability and the economic sustainability on bean production in Costa Rica. Since agroecosystem and economic sustainability are intrinsically interrelated (Figure 1.4), farmer surveys were conducted in conjunction with on-farm experiments. The transition from frijol tapado to frijol espeque was examined as a prototype of the transitions from traditional to higher-input technologies that are occurring throughout the developing world.

Specifically, the research was designed to answer the following questions:

1. How are bean yields, profits, and soil quality affected by the transition from frijol tapado to frijol espeque?

2. Can methods intermediate between frijol tapado and frijol espeque be used to produce a system which is both sustainable and productive?

3. Under what conditions should a transition from a traditional system not be expected nor promoted.

4. How can system sustainability be assessed within on-farm trials?

The remainder of this dissertation is a detailed examination of the factors affecting the sustainability of bean production on steep lands in the area of one small town, Pejibaye de Pérez Zeledón, located in the southern zone of Costa Rica.

In Chapter 2, the study location is described in detail. Rationale for using this location as a microcosm for technology-change processes throughout Costa Rica is presented. Questions left unanswered in the literature regarding frijol tapado and the transition to frijol espeque are investigated. Socioeconomic factors affecting technology adoption and the sustainability of both frijol tapado and frijol espeque are also discussed.

In Chapter 3, the effects on sustainability of different frijol espeque land use and land preparation practices are described. System sustainability was assessed based on studies designed to investigate differences in farmer practices of frijol espeque. Interactions between frijol espeque practices, erosion losses, bean growth and nutrient uptake, crop yields, and profits were investigated.

In Chapters 4 and 5, two on-farm experiments are described and discussed. The first experiment was designed to compare frijol tapado with four frijol espeque practices. The experiment was conducted on nine farms representing different lengths of fallowing and intensities of land use. Interactions between factors affecting yields, soil quality, and profitability were examined. The second experiment was designed to compare three frijol espeque land preparation methods and phosphorus fertilization within two environments: fallowed and continuously cultivated land. System sustainability in both experiments was assessed based on erosion losses, bean growth, nutrient uptake, nitrogen mineralization, soil aggregate stability, crop yields, weed and web blight infestations, and profitability.

Finally, Chapter 6 summarizes the work. The effects of technology change on the sustainability of the environmentally and economically fragile agroecosystem of steep lands are discussed. In addition, methods for evaluating the sustainability of farmers' practices and introduced technologies are recommended.

Figure 1.1a: Type I
Bean Growth Habit.
Determinate bush

Figure 1.1b: Type II
Bean Growth Habit.
Indeterminate bush.

Figure 1.1c: Type III
Bean Growth Habit.
Indeterminate prostrate.

Figure 1.1b: Type IV
Bean Growth Habit.
Indeterminate climbing.

Figure 1.1: Schematic representations of the four bean growth habits.
Source: Debauck and Hidalgo (1985)

Each dot represents approximately 100 hectares of beans.

Figure 1.2: Bean growing areas in Costa Rica.
Source: Schlotz (1983)

Figure 1.3a: Broadcasting frijol tapado

Figure 1.3b: Chopping residues after broadcasting frijol tapado

Figure 1.3c: Planting frijol espeque

Figure 1.3: Frijol tapado and frijol espeque planting methods.

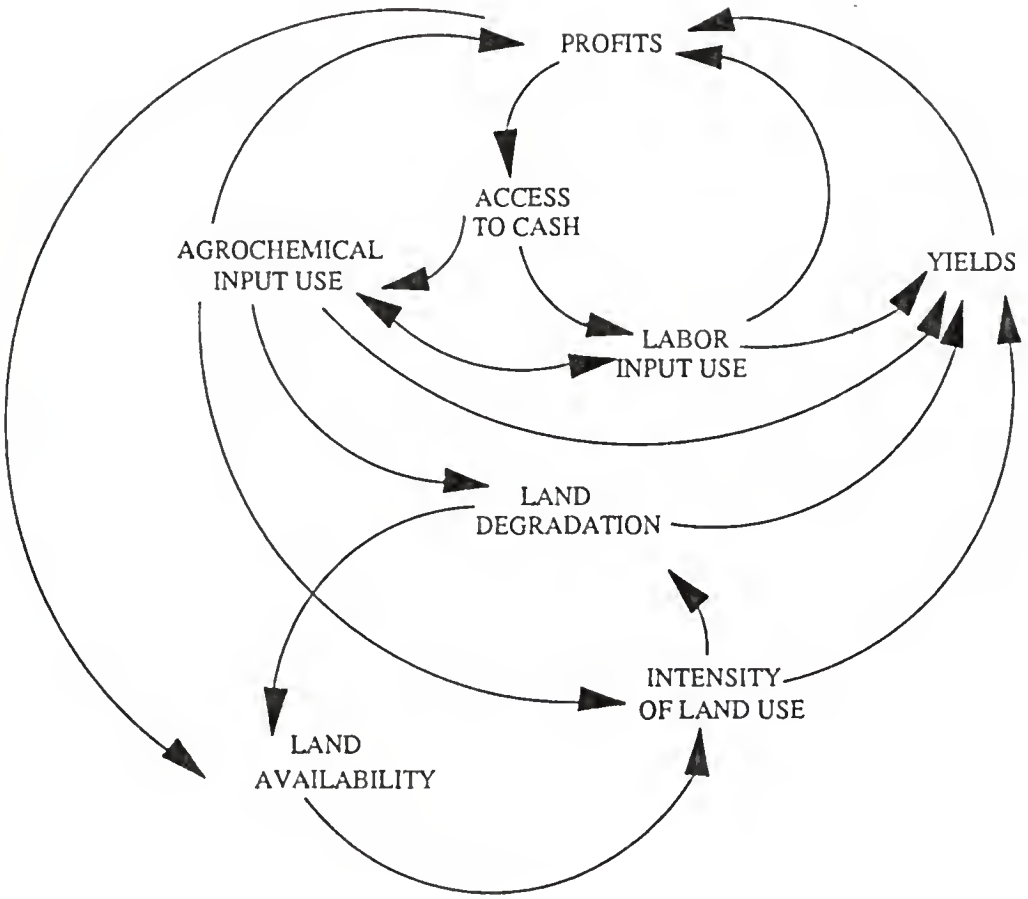


Figure 1.4: Agroecological and socioeconomic interactions affecting bean production on steep lands in Costa Rica.

Table 1.1: Comparisons of frijol tapado and frijol espeque.

	FRIJOL TAPADO	FRIJOL ESPEQUE
Planting Season	Veranero (October-January)	Inverniz (May-August)
Land Use Intensity	Rotation of one cropping season to 1-5 years of fallow	Continuous cropping, possibly with fallow rotation every 2-5 years
Land Slope	Steeply sloping	Moderately sloping
Land Preparation	No land preparation prior to planting	Residue chopped with machete then burned or piled
Seed Varieties	Traditional	Introduced
Bean Growth Habit	Indeterminate	Determinate
Planting Rate	35-50 kg/ha	20-30 kg/ha
Planting Method	Broadcast	Dibble stick planted
Input Use	None	Herbicides, fertilizers, and pesticides used
Labor Use	Only during planting and harvest	Land preparation, planting, input application, weeding, and harvest
Average Yields	569 kg/ha	941 kg/ha

Sources: Araya and Gonzáles (1987), Pachico and Borbón (1986) and von Platen and Rodríguez (1982)

Table 1.2: Agroecosystem factors of social value for frijol tapado and frijol espeque.

SOCIAL VALUE FACTOR	FRIJOL TAPADO	FRIJOL ESPEQUE
PRODUCTIVITY	low yields low land-use intensity	high yields high land-use intensity
STABILITY	diversity of income sources fallows promote plant diversity and stabilization of pest and predator populations	high labor inputs limits off-farm employment favors build-up of pest populations increasing input use may be needed to obtain stable yields
SUSTAINABILITY	mulch layer protects soil against erosion and compaction due to raindrop impact soil moisture conserved by mulch nutrient recycling enhanced by mulches and fallows	clear-field planting encourages soil erosion, soil compaction, and soil drying loss of organic matter and nutrients during land clearing and burning
EQUITABILITY	high returns on investment requires either ownership of sufficient land to fallow or rental of fallowed land does not require cash outlays	low return on investment intensified land-use can increase profits cash outlays for inputs may make farmers dependent on usurious money lenders

Based on Conway (1991).
Sources: Pachico and Borbón (1986), Araya and González (1987), Ramakrishnan (1988).

CHAPTER 2
PEJIBAYE DE PEREZ ZELEDON: A MICROCOSM FOR THE ASSESSMENT OF THE EFFECTS OF TECHNOLOGY CHANGE ON SMALL-SCALE FARMER PRACTICES IN COSTA RICA

An Introduction to Pejibaye de Pérez Zeledón

Reasons for the Choice of Pejibaye as a Study Location

Pejibaye de Pérez Zeledón is located in the southern bean-growing region of Costa Rica. During the 1940s, farmers abandoned the eroded and degraded lands of the Central Mesa for this fertile land full of promise. Fifty years later, bean farming is no longer considered profitable. Sons and grandsons of the original settlers are abandoning farming and returning to the Central Mesa to seek employment in the urban sector.

In Costa Rica, bean production occurs within the Central Mesa and throughout the half of the country bordering the Pacific Coast. From this vast area, Pejibaye de Pérez Zeledón was chosen for the focus of these studies because it is located in the center of an area of prime importance to national bean production. More than one-third of Costa Rica's beans are grown in the southern zone (Borbón, 1984). Between 55% and 65% of the beans produced during the first growing season are grown in the subdistrict of Pérez Zeledón (CNP, 1991). The northern zone of the country was rejected as a study site, although it also provides important contributions to the national bean production. The relatively level land around Los Chiles and Guanacaste, in the northern

zone, allows bean production to be highly mechanized and input-dependent. Frijol tapado and frijol espeque, the bean-growing technologies that serve as the focus of this study, are typically used by resource-poor farmers on steeply sloping lands. Bean growing in Pejibaye is primarily the work of small-scale producers farming marginal lands.

Pejibaye is an area in transition. From the onset of European immigration (in the 1940s) to the present, the population of the area has increased rapidly, due both to natural population increases and immigration. Construction, in the early 1980s, of an asphalt road between Pejibaye and the Inter-American Highway increased economic articulation between the center of Pejibaye and the urban sector of Costa Rica. Farmers living in the interior areas surrounding Pejibaye are only minimally articulated with the urban economy. This is because only rutted, seasonally passable dirt roads connect Pejibaye with the interior farming areas. The difference in economic articulation between areas close to Pejibaye and interior areas, no more than four kilometers from the center of town, resulted in distinct differences in technology-adoption patterns between farmers the two areas.

Since Pejibaye de Pérez Zeledón represents a transitional area but also is relatively accessible from San José, it has become the focus of various research studies. The area has served as the focus of studies conducted by students from the University of Costa Rica and the National University, as well as by researchers from the Instituto Interamericano de Cooperatión para la Agricultura (IICA), CIAT, Centro Agronomico Tropical de Investigación y Enseñanza (CATIE), MAG, and the Ministerio de

Planificación (MIDEPLAN). Researchers from U.S. universities also have used Pejibaye as a focus of their investigations.

The breadth of research previously conducted in this area provided background for the current study. It also confirmed that Pejibaye de Pérez Zeledón serves as a microcosm for demonstrating the effects of transitions in agricultural technologies on resource-poor farmers. In this study, socioeconomic surveys were conducted in conjunction with agronomic studies in order to understand constraints to adoption of introduced agricultural technologies.

Description of the Study Area

Pejibaye de Pérez Zeledón is located in the southern Pacific zone of Costa Rica between the El General River Valley and the Pacific Coast Range (Figure 2.1). The subdistrict boundaries extend from San Marcos de Pejibaye to El Aguila de Pejibaye (9° 10' N Lat., 83° 35' W Long. to 9° 05' N Lat., 83° 40' W Long.). Politically, Pejibaye is located within the district of Pérez Zeledón and the province of San José. According to the 1990 census, it had a population of 10,112 (Ministério de Economia Indústria y Comércio, 1991). The elevation of the study area ranges from 400 meters in the municipal center of Pejibaye to 1000 meters at the summit of the coast range. The area experiences a hyperisothermic temperature regime. A mean annual temperature of 22° C has been recorded at 950 meters (Barrantes et al., 1986). The soils in the area are of colluvial origin. On steep lands, the association of Tropepts, Humults, and Ustalts predominates (Corella, 1989).

The Pejibaye area receives approximately 2000 mm of rain annually, distributed in a bimodal monsoonal pattern. The first, less-intense rainy season begins in April and

continues through July. An unpredictable, short, dry season occurs between late July and early September. A second, more intense, rainy season begins in October and continues through December. The intensity and duration of the rainfalls are moderated by the area's location on the leeward side of the coast range. Between late December and mid-April, this region endures an extended and distinct dry period. The 1990 monthly rainfall totals for two locations in Pejibaye are presented in Figure 2.2.

Two planting seasons per year are observed. *Inverniz*, the wet harvest season, occurs during the first rainy season. *Veranero*, the dry harvest season, occurs during the second rainy season.

Maize and beans are the primary grain crops grown in the Pejibaye area. Relatively mild rainfalls and the existence of a mid-year dry season allows farmers to grow frijol espeque during the inverniz season. Mild rainfalls deter the spread of web blight, a fungal disease that is yield-limiting in this area. The mid-year dry season allows farmers, in most years, to harvest and dry their beans following the inverniz cropping season. Dibble-stick planted maize is grown during the veranero season as a rotation with frijol espeque. Despite high opportunity values for land, many farmers continue to plant frijol tapado during the veranero season.

Changes in Land Use and Bean Growing Practices

Causes and Consequences of Land Use Intensification

The first settlers arrived in Pejibaye in 1942. Rapid social and economic development of the area began around 1952, resulting in Pejibaye being designated as a legal district in 1966 (Sewastynowicz, 1986). Further commercialization of the area

became possible in the early 1980s with the completion of an asphalt road connecting Pejibaye with the Inter-American Highway and San Isidro. Before construction of this road, rutted road conditions and frequent bridge washouts often prevented travel during the rainy season.

In the less than 50 years since the arrival of the first settlers, most of the primary forests have been cleared for pasture use and crop production (Figure 2.3). The Land Settlement Laws stimulated deforestation. These laws gave settlers title to land that they had "improved" through land clearing and cultivation (Thrupp, 1990). Natural population increases and in-migration also placed pressure on land use. Early settlers purchased large tracts of prime agricultural land at low prices. Consequently, settlers who arrived later encountered high prices and decreased availability of land and were able to acquire only smaller tracts of more marginal land (Sewastynowicz, 1986). Even more importantly, cattle production displaced small-scale crop producers. Throughout the 1970s and 1980s the World Bank sponsored a farm loan program for cattle production (Annis, 1987). As a result, the amount of land in pasture increased while the amount of land used for crop production decreased (Censo Agropecurio, 1975; 1987). The percentage of farms of greater than 50 hectares also increased during this period while the percentage of farms with fewer than 5 hectares decreased (Chapman et al., 1983).

In 1984, a farming systems study was conducted by MAG in Guagural de Buenos Aires, located in the mountainous area adjacent to Pejibaye (Barrantes et al., 1986). Based on interview results, 24% of the farmers in this area owned between 0.5 and 1.0

hectares of land, 39% owned between 1.1 and 5.0 hectares, and only 6% owned more than 5 hectares of land. The remaining 30% of the farmers rented or sharecropped the land they cultivated. Tenancy agreements described were both exploitive and temporary. Tenants rented land for only one or two planting seasons. Sharecropping charges are either one-third or one-half of the obtained yield. This indicates that the farmers who farm sloping lands are those who are least able economically to implement capital-demanding conservation practices.

Government Programs to Increase Bean Production

The government of Costa Rica has implemented numerous programs designed to promote the production of basic grains and assist small-scale farmers. The most significant programs have been the CNP, formed in 1956, and the National Basic Grains Program, initiated in 1974. Acting as a mechanism for price stabilization, the CNP sets the price paid to the farmer for the production of basic grains. The National Basic Grains Program, funded in part by loans from the U.S. Agency for International Development (USAID), was designed to develop concrete actions in order to assure a substantial increase in the production of basic grains. To this end, an integrated program of farm loans and technology transfer was established (Chapman et al., 1983).

Despite rhetorical emphasis on assisting small-scale producers, these programs, in reality, served primarily to benefit medium to large-scale rice producers (Annis, 1987). Import-substitution policies were implemented. These policies provided subsidies to producers of commodity exports; specifically, rice and beef. They were not directed to, nor beneficial for, maize and bean producers.

In the area of Pejibaye, the effects of governmental programs aimed at increasing bean production have been mixed. During harvest, the CNP establishes a bean and maize-buying station in El Aguila de Pejibaye. This buying station regulates prices paid for beans and maize.

Nonetheless, many farmers still prefer to sell their products to private grain buyers. This is because the price actually paid by the CNP is usually lower than the announced price. At the time of purchase, standardized deductions are made for humidity and low quality. Private buyers do not deduct for these factors. Also, private buyers usually provide the grower with sacks and they purchase the product at the farm gate. This eliminates transportation costs between the farm and the CNP buying center, which the farmer would otherwise have to pay (Chapman et al., 1983).

An inter-institutional technology change and bean production improvement program for the subdistrict of Pérez Zeledón was initiated in 1982. The primary emphasis of this program was to encourage farmers to adopt frijol espeque production methods. Using the "training and visitation" extension method, MAG extension workers organized farmer groups and presented training seminars. To assist farmers in adopting this input-based production method, farm loans were made available through the BNCR and seed varieties were introduced through the CNP (Chapman et al., 1983).

Adoption of Introduced Bean Varieties

As a consequence of this inter-institutional effort, farmers adopted the introduced bean varieties, Talamanca and Brunca. By 1984, 80.8% of the farmers interviewed by Pachico and Borbón (1986) planted introduced bean varieties during the inverniz season,

while 73.3% planted these varieties, using frijol tapado, during the veranero season. The determinant Type I variety, Talamanca, was preferred for frijol espeque, while the indeterminate, Type II variety, Brunca, was preferred for frijol tapado production.

Adoption of the introduced bean varieties occurred simultaneously with adoption of frijol espeque. The use of agrochemicals also increased substantially between 1980 and 1985. Of the farmers interviewed in Pejibaye, only 12% used fertilizers and 30% used herbicides for bean production in 1982 (Chapman et al., 1983). By 1985, 73% of the farmers from the adjoining region of San Isidro used fertilizers and 65% used herbicides (Borbón, 1984). Pesticides were used by 81% of these farmers.

Frijol espeque yields increased 35% due to adoption of introduced varieties while frijol tapado yields only increased 25% (Pachico and Borbón, 1987a). Average yields reported by farmers planting Talamanca were 964 kg ha^{-1} for frijol espeque grown during the inverniz season and 581 kg ha^{-1} for frijol tapado grown during the veranero season (Ballestero, 1985). Farmers cited high yields, disease resistance, and erect growth habit as reasons for adopting introduced bean varieties (Borbón, 1984).

Adoption of introduced varieties for frijol tapado remains less than for frijol espeque. Only 50% of the farmers living in a predominantly frijol tapado growing region adopted introduced varieties, compared to 96% of the farmers living in a predominantly frijol espeque growing region (Ospina, 1990). Non-adoption by frijol tapado farmers may be due to farmer preference for traditional varieties in this planting system. Farmers consider traditional varieties to be more resistant to adverse conditions, and better adapted to local environmental conditions, than the introduced varieties

(Ballestero, 1985). Lack of adoption of introduced varieties in frijol tapado production may also be due to a lack of interaction between frijol tapado farmers and extension agents. Sterling (1981) noted that 26% of the farmers growing frijol espeque had contact with extension agents while none of the frijol tapado farmers reported contact with extension workers.

Bean Production Problems

Input-based cropping methods are designed to allow farmers to use their land more intensively. During the 1950s, farmers in the vicinity of Zapote de Pejibaye planted a crop-fallow rotation. Typically, this rotation consisted of two years of cultivation followed by 6 years of fallow. By 1979, due to decreased farm size, over 50% of the farmers no longer felt able to include a fallow season in their cropping cycle (Solano, 1980). Increased land use intensity also forced farmers to use more capital-intensive methods. It also resulted in decreased sustainability, due to diminished agroecosystem diversity and increased soil losses due to erosion.

Pest and disease attacks have a critical effect on bean production. Severe attacks by slugs and corn rootworm (Diabrotica spp.) were noted by local farmers as the primary cause for losses in bean yields (Borbón, 1984). Pathogens, especially web blight, also reduce bean yields in this area. Other pathogen problems reported by farmers include angular leaf spot (Isariopsis griseola), rust (Uromyces phaseoli), and anthracnosis (Colletrichum lindemuthianum) (Ballestero, 1985). Weed infestations are also a common problem locally (Barrantes et al., 1986).

Other production problems reported by farmers included lack of capital, inability to obtain necessary hired labor, and either heavy rains or severe droughts (Barrantes et al., 1986).

Study Objectives

Previous socioeconomic studies conducted in this area have focused on changes in farming practices since the time of settlement (Solano, 1980), economic comparisons of frijol tapado and frijol espeque production (Borbón, 1984; Pachico and Borbón, 1987a and 1987b), economic impacts of adopting introduced bean varieties and frijol espeque planting methods (Chapman et al., 1983; Ballestero, 1985; Ospina, 1990), and agronomic problems experienced by frijol espeque producers (Barrantes et al., 1986).

The present study was designed to identify factors affecting the sustainability of both frijol tapado and frijol espeque production on steep lands. The sustainability of these systems is affected by a combination of social, economic, agronomic, and ecological factors. This chapter is used to investigate the socioeconomic factors affecting the sustainability of bean production practices. Interviews were conducted to identify factors affecting the short-term profitability and the long-term sustainability of bean farming. Additionally, factors affecting farmers' decisions to change technologies were investigated. Based on results from the socioeconomic studies, experiments were designed to test the agronomic sustainability of bean production. Technologies that take advantage of the opportunities, while recognizing the constraints, within the agroecosystem were recommended.

Methodology

Surveys

Three sets of formal interviews were conducted; initial base-line interviews, economic surveys with frijol espeque growers, and economic surveys with frijol tapado growers. Informal surveys and discussions were also conducted with key informants including extension agents, agrochemical input dealers, and large landowners. A summary of the surveys conducted is shown in Table 2.1.

Initial surveys. Initial interviews were conducted during March and April, 1990. A random sample of 51 steep-land bean farmers from 10 barrios of Pejibaye de Pérez Zeledón were interviewed. All farmers lived within 8 kilometers of Pejibaye (30 minutes by motorcycle during the dry season). Questions were designed to obtain information regarding land ownership, bean-growing practices, and attitudes concerning soil-conserving agricultural practices. Agronomic questions focused on land-preparation methods and the use of fertilizers, introduced seed varieties, pesticides, and herbicides. Farmers were asked to describe agronomic problems experienced and changes implemented in their agricultural practices. They were also asked to describe their perception of the future for bean production in the area (Appendix A).

Costs and returns for frijol espeque production. In July and August, 1990, following the inverniz harvest season, 31 frijol espeque farmers: 19 tenant farmers and 12 farmer-landowners were interviewed. Farmers were asked to list their production costs. Specifically, questions were designed to determine the use of commercial inputs, inputs of hired and family labor, tenancy costs, and marketing costs. Respondents also

were asked about bean production problems encountered, bean yields obtained, marketing channels used, and off-farm labor activities (Appendix B).

Costs and returns for frijol tapado production. In December 1990 and January 1991, following the veranero harvest season, 28 frijol tapado farmers from the Pejibaye area were interviewed. The Pejibaye area is relatively accessible, and introduced technology-adoption is high. To obtain a comparison with frijol tapado use in less accessible areas, where introduced technology-adoption is low, 28 farmers in Guagural and San Vito were also interviewed. Farmers in these areas lived more than one hour by motorcycle (during the dry season) away from a commercial center. Muddy roads or swollen rivers often leave these areas isolated during the veranero growing season.

Frijol tapado farmers were asked questions similar to those asked of frijol espeque growers. In addition, these farmers were asked to quantify profits from other on-farm or off-farm labor activities in which they engaged during the veranero growing season. Farmers were also asked questions to determine what factors affected their decisions to continue planting frijol tapado (Appendix C).

Informal discussions were conducted with large land owners, tenant farmers, extension agents, input vendors, and bank officials throughout the study period. Landowners were asked about changes in the amount of land dedicated to bean production, and about modifications of their tenancy and fallow-use practices. Tenants were asked about the length of their tenancy agreements and about the form of tenancy agreement they had with their landlord. Tenants were also asked if they would alter their farming practices if they were farming their own land rather than sharecropped

land. Extension agents, input vendors, and bank officials provided information about the services they provided to the farmers and about the farmers' use of their services. These discussions were used to determine the extent of interaction between various sectors of the agricultural community and to delineate likely changes in the farming community and farming practices.

Measuring the Economic Impact of Technology Change

Bean production is only one of several economic activities for farmers in the Pejibaye area. No attempt was made to compute the gross family income from all on-farm and off-farm activities of the farm families interviewed.

The economics of bean production were calculated according to the following criteria:

Labor value was calculated based on the number of *jornales* spent on each of the following activities: land-preparation, planting, application of inputs, weeding, harvesting, seed cleaning, and marketing. A jornal is a farm-labor day, equivalent to approximately 6 hours. Each jornal was valued at 350 Colones (107 Colones = $1 US, 1-1-91). Family labor was valued at the same rate as hired labor.

Input costs included costs for purchased agrochemicals, seeds, sacks, and marketing transportation costs. The value of seeds saved from the previous harvest was based on the official CNP price paid for beans during the previous growing season. For tenant farmers, input costs also included the value of the beans paid to the landowner as rent. For landowners, costs of landownership and taxes were valued at 2000 colones per hectare. This was roughly based on the land valued at 40,000 colones per hectare, 15

years for payment, and two payments per year. For most farmers, this value is considerably higher than their actual expenses, since the land was acquired when land prices were lower.

Gross income was based on the *quintales* of beans harvested multiplied by the official CNP price per quintal. One quintal is equal to 45 kilograms.

Other economic factors calculated included net income, (cost of family labor was not included as input costs), the ratio of gross income to input costs, and the ratio of net income to jornales of family labor (the value of each jornal of family labor).

Statistical Analyses

Statistical differences between bean-production practices and economic indicators were assessed using regression and t-test analysis methods of the statistical package SAS (SAS, 1985).

Results and Discussion

Overview of Farming Practices

The farming community of the Pejibaye area consists of many small-scale landholders and tenants living as neighbors to a few large landholders. All farmers selected for interviews in this study planted a maize-bean rotation on steep slopes. Of the 51 farmers initially interviewed, 18 (35%) planted frijol espeque as sharecroppers while 33 (65%) owned the land they farmed. Over 70% of both tenant farmers and farmer-landowners planted three hectares or less of beans (Table 2.2). Frijol tapado was

planted during the veranero season by 50% of the tenants and by 42% of the landowners.

Farming calendar. The calendar of activities of a farm family is determined primarily by annual rainfall patterns and the production activities required for the crops, trees, and livestock produced. The temporal interactions of the labor activities and economic flows of the farm family are shown graphically in Figure 2.4. The availability of high-value, off-farm or on-farm labor opportunities may compete with bean production activities. Non-agricultural household expenses may not only force farmers to sell produce, but may also prevent farmers from purchasing agrochemicals or labor inputs. For many farmers, an important seasonal household cost is the purchase of school uniforms and notebooks at the onset of the school year in March.

Alternative labor activities for tenant farmers. Tenant farmers divided their labor time among bean production activities, work as day laborers, and harvesting coffee. During the inverniz growing season, 65% of the tenant farmers worked as day laborers on other farms. During the veranero growing season, 100% grew maize, 59% worked as day laborers, and 88% engaged in coffee harvests (Table 2.2). Tenant farmers harvested coffee either in the Pejibaye area or as temporary migrants to the Central Mesa. Local coffee harvests extended from September to early December. The coffee harvests of the Central Mesa extended from December to February. Women and children as well as men participated in the local coffee harvests. Usually only men migrated out of the area to pick coffee. Twenty-eight percent of the farmers who planted beans as tenants produced coffee on their own land.

Alternative labor activities for landowners. Landowners did not engage in off-farm employment, but instead divided their labor between bean production and other on-farm activities (Table 2.2). During the inverniz growing season, landowners chopped pastures, pruned and weeded coffee, and repaired fences in addition to frijol espeque production. During the veranero growing season, agricultural labor activities of landowners included maize production, harvesting coffee on their own land, chopping pastures, and caring for cattle.

Tenants

Tenancy agreements. Tenant farmers grew beans according to two tenancy arrangements; halves and thirds. According to the thirds agreement, the landlord provides the tenant with the use of the land. In return, the tenant is responsible for the costs of all commercial and labor inputs, and pays the landlord with one-third of the crop yield. According to the halves agreement, as described by Barrantes et al. (1986), the landlord provides the land and pays for half the costs of fertilizers, fungicides, and insecticides. In return, the tenant is responsible for the entire cost of herbicides, half the cost of fertilizers, fungicides, and insecticides, and for all of the labor costs. Crop yields are split equally between the landlord and tenant.

Based on interviews with tenant farmers, practice of the halves agreement is quite variable. Usually, instead of providing fertilizers, fungicides, and insecticides, landlords only assist their tenants in the purchase of herbicides. Several tenant farmers complained that they were not able to use agrochemical inputs to produce their crops because landlords were unwilling to pay their half of the cost.

The thirds agreement was used by 71% of the tenants interviewed (Table 2.2). It is the agreement preferred by most tenants and landlords. Tenants preferred this agreement because it provides them with more freedom in their choice of farming practices and is less costly. Landlords preferred it because it is less economically risky in the event of a crop failure.

Duration of tenancy agreements. Tenancy agreements are generally of short duration. Over 91% of the tenants interviewed held tenancy agreements for 5 years or less (Table 2.2). One-third of the tenants had land use agreements for 2 years or less. The short duration for lease agreements on steeply-sloping lands is due to perceived decreases in production and profitability after two to three years of continuous cropping. Following the expiration of tenancy agreements, leased land is either fallowed or placed into other agricultural uses. Of the landlords interviewed, 70% indicated that, within the past ten years, they had decreased the amount of land available to tenants for bean production. Simultaneously, they had increased the amount of land in pasture.

As a result of the conversion of formerly sharecropped land to pasture use, 40% of the tenants encountered difficulties in finding land to rent. More than two-thirds of the tenants also had difficulties finding fertile land or land close to where they live.

Perceived decrease in the profitability of bean production. Most tenants said their production costs have increased while yields have decreased. Reasons for decreased profitability of bean farming most often noted were: overuse of land (65%), high input costs combined with low bean prices (59%), and pest and disease infestations (46%). All tenants indicated lack of land ownership as one of their greatest problems.

Having to give at least one-third of the bean yield to the landlord while also paying for most or all of the production costs was the principal reason tenants gave for lack of bean-growing profitability. One farmer noted, "due to the difficult economic situation tenant farmers are facing today, I do not feel that we can do anything to improve our situation."

The current economic situation may encourage tenants to use land-degrading farming practices. Over 83% of tenants cleared land for frijol espeque production by burning. Most of these tenants felt that fire "sterilizes" the land. They also admitted that the farming practices they used on rented land abused or degraded the land. Half of the tenant respondents said that, if they had their own land, they would not burn the land but would instead use soil-conserving measures.

Despite the decreasing profitability of bean farming, most tenants felt that they had no option but to continue farming. More than 83% of the respondents indicated that they wished to quit farming and 70% did not want their sons to be farmers. They hoped their sons would find less demanding and less risky work.

According to respondents, many tenant farmers already have left farming to look for work in the urban sector or have moved out of the area in search of more fertile lands. Typically, the sons who were continuing farming were described as those who "do not like to study." That is, they were either disinterested in studying or unable to do well enough in school to obtain permanent off-farm employment.

The out-migration of tenants appears to have created a circular problem. Several large owners of more remote farms had difficulties in obtaining tenants to farm their

land. As a result, they increased the amount of land for pasture use and decreased the amount of land they made available to tenants.

Farmer-Landowners

The majority of farmer-landowners owned small tracts of land and engaged in diverse agricultural activities. Over one-half of the landowners owned less than 7 hectares of land. Coffee was the major alternative crop for small holders (less than 7 ha) since it has the potential to produce high economic returns per hectare. Conversely, due to the low labor inputs required, larger landholders used a majority of their land for cattle production. All landholders owning more than 14 hectares of land had some land in pasture. Other commercially important crops produced by landowners included rice, tomatoes, sugarcane, and cacao. Crops grown for home use included bananas, cassava, and fruit trees.

Perceived decrease in the profitability of bean production. Similar to tenant farmers, farmer-landowners felt that bean production was becoming less profitable. Reasons given for the decreasing profitability of bean production included: high costs of inputs combined with low prices paid for beans (82%), decreasing soil fertility (73%), disease and pest infestations (64%), and lack of government assistance (64%). Due to the perceived lack of profitability for bean growing, many landowners have placed much of their former bean land into coffee, cattle, or vegetable production. Some landowners, in desperation, have tried to extract themselves from debt by growing marijuana (R. Floras, personal communication). Survey results also showed that the percentage of land in bean production decreased as farm size increased. Although farm size ranged from

1.4 to 100 hectares, land devoted to bean production ranged only from 0.7 to 7.0 hectares.

Frijol Espeque

Agrochemical input use. Both MAG and CNP promoted the use of frijol espeque. These organizations encouraged farmers to use certified seeds, fertilizers, and pesticides in frijol espeque production. Recent MAG recommendations also encouraged farmers to leave crop residues on the ground in order to reduce erosion losses. Due to financial constraints, however, most farmers did not manage frijol espeque according to extension recommendations. Although all landowners and tenants used burn-down herbicides (Table 2.3), only 83% of the landowners used fertilizers. Less than 25% of the landowners used a complete package of agrochemicals in their production of frijol espeque. Of the tenant farmers, less than one-third used either fertilizers, fungicides, or insecticides.

Two-thirds of the farmers used fire to clear their land prior to planting frijol espeque. Reasons given for land burning included decreased labor costs and a belief that fire helps control pest and disease infestations, especially slugs.

Most of the farmers have adopted introduced seed varieties for frijol espeque production (Table 2.3). Over 80% of all respondents used either Talamanca or Brunca seed varieties. Although these are not the only varieties of introduced seeds, they are the most recently released varieties and the varieties most commonly sold as certified seed by the CNP. Only 18% of the landowners purchased seed from the CNP, while none of the tenants interviewed used certified seeds. Farmers who did not purchase

seeds from the CNP used seeds saved from the previous harvest. Farmers often used a combination of seed varieties. Almost one-half of the respondents used Talamanca or Brunca in combination with either traditional varieties or previously released introduced varieties. Although some farmers blended seed varieties, farmers usually selected specific seed varieties depending on the slope, soil fertility, or fallow growth of each portion of the field.

Labor inputs. Labor inputs for frijol espeque production included land clearing, planting, application of fertilizers, herbicides, and pesticides, harvesting, threshing, drying, and marketing. Family labor was generally limited to fathers and sons or associations between brothers. Wives or daughters assisted in fertilization and harvest activities according to 38% of the respondents. Hired labor was used by farmers to assist primarily with land preparation and planting. One-fourth of farmer-landowners used hired labor to assist with frijol espeque activities. Tenants were more than three times as likely to employ hired labor as were landowning farmers. Almost 80% of the tenant farmers used hired labor in combination with their own labor (Table 2.3).

Production problems. Web blight was reported as the major disease problem by 70% of all farmers interviewed, while slugs were mentioned as a pest problem by 51%. The other major production problem, mentioned by 65% of the farmers, was environmental; the sprouting of beans in the pods due to harvest-season rains.

Frijol Tapado

Input use. Frijol tapado is a traditional planting method utilizing minimal agrochemical and labor inputs (Table 2.3). Labor inputs for frijol tapado were required

only during the planting and harvest seasons. This allowed frijol tapado farmers to devote their time to other on-farm and off-farm labor during the period of bean growth.

Agrochemical inputs typically are not used in the production of frijol tapado. The introduction of slugs into the region, however, induced 35% of frijol tapado farmers to apply molluscacides to their fields. The application rate used was between 10% to 25% of the recommended rate. According to farmers, slugs presented a greater problem in annual frijol tapado fields than in fields that had been left in fallow for more than two years.

Preferred fallows for frijol tapado. Farmers preferred using land having an easterly exposure for frijol tapado production. This orientation allows for the early morning sun to dry the land, resulting in a decrease in the transmission of web blight and other fungal diseases. Land that had been in fallow for at least two years was preferred by 68% of the frijol tapado growers.

Preference was also given to land where slow-growing perennial plants dominated the fallow growth. Many farmers mentioned three plants in the Compositae family; tora (Verbesina sublobata), tuete (Veronia spp.), and paira (Melanthera aspera), as indicators of soil fertility. Through discussions with farmers and observations of frijol tapado fallows, a list of plants dominating fallows of various age was developed (Table 2.4). Plant species and associations commonly associated with frijol tapado fallows are illustrated in Figure 2.5.

Duration of fallow and tenancy. The length of the fallow used between successive croppings of frijol tapado depended on the size of the landholding, competing

farming activities, the distance of the farm from markets, and the customs of the farmer. Since frijol tapado is a land-use extensive farming method, only farmers who owned more than five hectares of land were able to grow frijol tapado on their own land. Farmers who owned smaller tracts of land grew frijol tapado as tenants.

Of the tenant farmers, 83% experienced difficulty in locating good-quality land for tapado use. Despite expressed preferences for an extended fallow, most tenants indicated that they were willing to "plant frijol tapado in whatever type of fallow they could obtain."

Production problems. Production problems reported for frijol tapado were similar to those reported for frijol espeque: slugs, web blight, and seed sprouting. Slugs were mentioned as a problem in frijol tapado bean production by 44% of the farmers interviewed, while web blight was a problem for 25% of the respondents. The problem of web blight was less for frijol tapado compared to frijol espeque. Similarly, only 27% of the farmers mentioned sprouting beans as a frijol tapado production problem, compared to 65% who noted it as a problem for frijol espeque. The combination of a mulch cover and lower inoculum levels in frijol tapado fields was responsible for the decreased incidence of web blight. The more favorable weather during the frijol tapado harvest season compared to that of frijol espeque decreased problems associated with sprouting beans.

The Transition from Frijol Tapado to Frijol Espeque

Based on farmer interviews, a decision tree (Gladwin, 1989) was developed summarizing the major factors affecting farmers' decisions to use frijol tapado or frijol

espeque (Figure 2.6). The decision to plant frijol tapado was based on climatic factors, land availability, availability of high-value off-farm employment during the frijol tapado growing season, land slope, access to inputs, and farmer custom. Frijol tapado is favored because of the availability of excess land, low access to economic resources and financing, remoteness from sources of inputs and marketing centers, high opportunity values for other on- or off-farm labor activities, and heavy rainfall. Frijol espeque is favored because of high land-use competition, accessibility of inputs and markets from the farmstead, and relatively more cash and labor availability.

The principal influencing factor was climatic. Farmers growing beans in monsoonal areas practice frijol tapado during the veranero season. Heavy rainfall during this growing season prohibits land-burning. The rainfall erosivity is also greater during this growing season than during the inverniz season. By using frijol tapado, a mulch layer is retained on the soil surface to protect against raindrop impact and the associated soil losses due to erosion as well as the dissemination of fungal inoculum.

Due to the high opportunity value for labor during the veranero growing season, frijol espeque is not commonly practiced during this season. Instead, the adoption of frijol espeque is usually accompanied by a transition from using the veranero season to using the inverniz season as the principal bean growing season. Similarly, the introduction of high yielding maize varieties resulted in a change in the primary maize growing season from the inverniz to the veranero season. In contrast to the traditional varieties, ears of introduced maize varieties are highly susceptible to rot if left on the stalk during the rainy season. Farmers who engage in multiple on-farm and off-farm activities

double-over the maize stalk and do not harvest the ears until they are finished with more urgent activities. Due to the extended dry period at the end of veranero, introduced maize varieties can be left safely in the field at the end of the growing season. Thus, genetic characteristics of the introduced varieties of beans and maize have contributed to the reversal of bean and maize growing seasons.

Adoption of frijol espeque during the inverniz season is precluded in areas where continuous rainfall at the end of this season present a high risk of crop loss due to bean sprouting. Pejibaye is an example of an area with a moderated monsoonal climate, while San Vito and Guagural experience continuous rainfall. Consequently, Pejibaye is a high adoption area while San Vito and Guagural are low adoption areas.

Farmers in the Pejibaye area adopted frijol espeque as the primary mode of bean production while continuing to use frijol tapado as a secondary source of beans and cash. Frijol tapado was grown in this area primarily as a subsistence crop. Only one-half of the farmers sold a portion of their frijol tapado crop. The remainder grew frijol tapado for home consumption and to produce seed for frijol espeque. Since farmers used frijol tapado to augment their seed stores for frijol espeque, over 60% of frijol tapado farmers used introduced seed varieties either exclusively or in combination with traditional varieties.

Farmers also used frijol tapado as a crop producing method for bringing forested or fallowed land into agricultural production. Consequently, only 38% of the parcels used for frijol tapado were returned to fallow directly following the frijol tapado harvest (Table 2.5). When used as means of land clearing, frijol tapado was planted concurrent

with clearing fallow growth during veranero. Following the dry season, weed regrowth was cut, then the weeds and mulch residues were burned. The chopped residues were burned to increase the availability of plant nutrients and to provide a clear field for planting frijol espeque during the inverniz season.

Alternatively, land was used for a frijol tapado and pasture rotation. A field is used for several years as an unimproved pasture, then placed into fallow for one to two years to regenerate soil fertility and decrease weed growth. Prior to returning the land to pasture use, the fallow is chopped concurrent with the planting of frijol tapado.

Farmers in the areas of San Vito and Guagural planted frijol tapado either exclusively or as part of a rotation with frijol espeque, maize, and land fallowing. All farmers in these areas continued to utilize a crop-fallow rotation (Table 2.5). Most farmers produced frijol tapado for sale as well as for subsistence use. They also used traditional seed varieties primarily. The preferred traditional varieties in both regions were Chimbalo Rojo, Chimbalo Negro, and Viña Blanca. These varieties are classified as Type III and Type IV. Farmers who used traditional varieties noted the higher resistance to pests and diseases of these varieties compared to the introduced varieties. Farmers who grew frijol tapado for market grew Chimbalo Rojo, since a premium price was paid for red beans. Only 8% of the farmers used introduced varieties exclusively.

Economic Aspects of Frijol Espeque and Frijol Tapado

Frijol espeque required a higher level of economic investment and provided higher gross returns than frijol tapado (Table 2.6). Although differences were not significant, the average jornales of labor reported for frijol espeque production were

almost double the labor inputs used for frijol tapado. The distribution of labor, throughout the growing season, for the two bean-growing practices also differed. Frijol espeque requires crop management activities while frijol tapado does not involve any labor inputs during the growing season. Average costs for agrochemicals and seeds for frijol espeque were over four times more than for frijol tapado. The average yields reported for frijol espeque were more than two-and-one-half times those obtained from frijol tapado. The highest yields reported for frijol espeque (1300 kg/ha) were more than three times higher than the highest yields reported for frijol tapado (383 kg/ha). Near-total crop losses, however, were reported for both planting systems.

Landowners spent significantly more on commercial inputs and obtained higher yields for frijol espeque than did tenants. No significant differences in bean yields for landowners compared to tenants were obtained for either frijol tapado or frijol espeque when the planting methods were analyzed separately. When comparisons were made across planting methods, yields obtained by landowners were significantly higher than those obtained by tenants.

Due to the high rental costs, the value of each jornal of family labor in frijol espeque production was three times more for landowners than for tenant farmers. For landowners, the value of each jornal was over twice the amount that they could have obtained working as a day laborer on another farm (350 Colones/ jornal). For frijol tapado production, the value of their labor was slightly more than that paid to day laborers. For tenant farmers, the net returns obtained per jornal for both frijol tapado and frijol espeque were less than the wage paid to a day laborer. No significant differences

in the value of each jornal were obtained when comparisons were made between frijol espeque and frijol tapado. For landowners, the average value of each jornal of frijol espeque labor was over twice that of each jornal of frijol tapado labor. For tenants, the value of each jornal of frijol tapado labor was slightly higher than the value of each jornal of frijol espeque labor.

Conclusions

Land Tenancy and the Adoption of Frijol Espeque

Economic surveys results showed that the adoption of frijol espeque benefitted landowners more than tenants. Landowners were able to apply more commercial inputs to their frijol espeque fields due to their greater access to economic resources. Since they incurred greater hired-labor expenses, the total costs incurred by tenants were often higher than the costs incurred by landowners. Tenant farmers employed hired labor in order to decrease the number of visits they needed to make to fields far from their homes, or in order to free up their time so that later they could sell their own labor. As a result of low yields, high labor costs, and high rental expenses, the net returns obtained by the tenant farmers were less than one-half of the net profits obtained by landowners.

As the profitability of bean production declines, larger landowners have the opportunity to transfer their land out of bean production and into more profitable commodities; coffee or cattle. Depending on farm size and access to economic

resources, landowners also can increase the sustainability of bean production by adopting accelerated fallows, labranza cero practices, or agroforestry techniques.

The options available to the one-third of the bean farming community who are tenants are much more limited. Tenant farmers received significantly lower returns for their bean growing activities, yet often did not have the option of changing to a more profitable commodity. This was especially true for tenants living in areas with low accessibility to markets. For this sector of the farming community, the most viable alternative for increasing household incomes was to leave farming and obtain a permanent labor position elsewhere. Although the majority of tenant farmers expressed a desire to leave farming, they continued to engage in bean farming due to a lack of permanent labor opportunities.

Tenants who remain in farming can try to sharecrop land that was recently fallowed or that has relatively fertile soils. In this way, they increase their chances of obtaining saleable yields without having to purchase fertilizers, insecticides, or fungicides. The practice of extracting plant nutrients through farming without subsequent replacement through fertilizer use can increase the profitability of bean production for resource-poor farmers. It also enhances soil degradation and decreases sustainability.

Tenants can also use low-input, low-risk farming practices. For them, frijol tapado represented an economic safety net for subsistence food source and increasing household income. Although farm families were able to obtain relatively high profits from coffee harvests, most frijol tapado farmers needed to both harvest coffee and grow frijol tapado. The receipts from the coffee harvest paid for household expenses during

the veranero growing season, while yields from the frijol tapado harvests supported the family during the extended dry season.

These results are in contrast to the results reported by Pachico and Borbón (1986) who concluded that frijol tapado was more important for large-scale producers than for small-scale farmers. The present study indicates that frijol tapado was used for seed and subsistence production by farmers with landholdings sufficient to place land in fallow. As the profitability of bean production decreased, however, landowners removed their land from frijol tapado use and placed it into coffee and cattle production. In contrast, diminished land availability for frijol tapado production displaced tenants from farming and caused increased out-migration to the Central Mesa in order to pick coffee, or to Limón to work in the banana plantations.

Complementary and Competitive Interactions between Frijol Tapado and Frijol Espeque

In the Pejibaye area, frijol tapado and frijol espeque exist as both complementary and competitive forms of production. Over 40% of all bean farmers practiced both frijol espeque and frijol tapado. The complementary nature of the two bean planting practices was indicated by the use of the same varieties of seeds for both frijol tapado and frijol espeque. Also, frijol tapado was used as a transition between land fallowing and frijol espeque production. Landowners who rented land to tenants for frijol tapado production, however, often were more interested in the land clearing accomplished by the frijol tapado activities than in the bean yields they received. Consequently, much of this cleared land was subsequently removed from frijol tapado production after harvest.

Limitations to Increasing the Profitability of Bean Farming

The actual frijol espeque practices used by small-scale farmers did not reflect their knowledge about either soil conservation or input-use practices. Instead, it reflected their conservative use of available resources. This contradiction between knowledge and practice was summed up by one farmer. He said, "There are many inequalities; we want to use recommended methods but we cannot because we do not have sufficient resources." Most frijol espeque farmers felt that pest problems could be decreased and yields increased by not burning the land, and by using instead labranza cero or a regular fallow rotation. Use of rotations, however, was considered by many small-scale landowners as "a luxury." Similarly, many farmers wanted to adopt labranza cero techniques but felt unable to do so because of the additional time required to plant within residues compared to planting a cleared field.

Availability of cash, labor, and land resources for bean production was limited by the need of the farm family to use these resources for other purposes (Figure 2.7).

Monies for chemical inputs competed with monies for food and school expenses since the frijol espeque season begins at the end of the long, dry, "hungry" season and concurrent with the beginning of the school year. The onset of school also prevented children from assisting their parents in bean production activities. In addition, labor availability for bean production, especially during the veranero growing season, was limited by higher opportunity values for labor in other on- and off-farm activities. Land availability for bean production was limited by the high opportunity value for land in vegetable production and by farm loan programs promoting the production of cattle and

coffee. The farm size and the opportunity value for land use in other agricultural activities also affected the duration and frequency of the fallows used.

Changes in political policies have affected the profitability of bean production. In an effort to reduce government costs and decrease redundancy in government services, the extension arm of the CNP was dismantled and the BNCR offices in small towns, including Pejibaye, were closed in 1990. As a result, the rural population became increasingly disarticulated from the urban market economy and farmers became increasingly dependent on local vendors for loans and marketing outlets. Meanwhile, rapid inflation resulted in a corresponding decrease in the price of beans while fertilizer prices remained relatively stable (Figure 2.8). These factors further decreased the margin of profit which farmers receive for their bean crops.

Options for Increasing the Profitability of Bean Farming

Farming systems and farmer-first methodologies were developed in an attempt to direct development programs at the needs and constraints of the poorest sector of the farming community. These methods stress the use of alternative organizational forms, management techniques, and research methods appropriate to a people-centered development and adapted to the context of the area of project implementation (Chambers, 1986). Bureaucratic constraints, unfortunately, often have resulted in development organizations becoming promoters of predetermined technologies in pre-identified target areas rather than as catalysts for change in self-identified communities (Hellinger et al., 1988).

Currently, several development organizations are involved throughout Costa Rica in the promotion of agroforestry and accelerated fallow technologies designed to increase the sustainability of frijol espeque production. In contrast, very few organizations are concerned with the opportunities and constraints of frijol tapado production. Similarly, few development or research programs have addressed the bean production problems of tenant farmers.

The current lack of sustainability of bean production in Pejibaye is caused by a combination of agronomic, economic, and political factors. Agronomically, intensification of land use resulted in the adoption of land use practices inappropriate to the steeply sloping terrain of this area. Economically, many farmers are unable to afford inputs required to make continuous cropping practices sustainable. Politically, governmental policies benefitted producers of export commodities and larger landholders at the expense of producers of subsistence crops and resource-poor farmers. Also, a history of mismanagement or partial implementation of programs by MAG and CNP extension offices discouraged farmers from associating with these organizations. Several farmers said they felt that extension agents were incompetent or "spent all their time driving around in expensive vehicles visiting the richest farmers."

Agronomic solutions to political problems are usually not as sustainable as agronomic solutions to purely agronomic problems. Unfortunately, many of the agricultural problems facing resource-poor farmers in the developing world have political components. Small-scale bean farmers in the Pejibaye area are involved in a cycle of decreasing sustainability. As population pressures and inequities of land tenure relations

increase, the availability of land decreases. This encourages small-scale farmers to use intensive land use practices that are inappropriate for marginal lands. While these practices may produce higher yields in the short-run, in the long-run they encourage soil degradation and result in farmers having to apply increasing levels of inputs in order to obtain decreasing yields. This results in a decline in both the economic and agroecological sustainability of the farming practice.

As a result of the cycle of degradation in which small-scale and tenant farmers must operate, recommendations that can be adopted by them may not offer long-term sustainability. Economically viable options available to these resource-poor farmers include:

1. Planting frijol espeque on fallowed land using a minimum of fertilizers and pesticides.
2. Planting frijol tapado
3. Using an intermediate technology that would be responsive to commercial inputs but would require a minimum of labor expenditures during the growing season.

To test the sustainability of these options, agronomic experiments were conducted. Labranza cero was chosen as the intermediate technology to be tested. It was chosen because the mulch cover would maximize nutrient recycling within the system, decrease soil losses from erosion, minimize the time required for manual weeding activities, and protect against bean production losses due to web blight. Planting of beans in a straight row rather than broadcasting seeds under a mulch cover should

increase the bean emergence percentage and allow farmers to manage their crops more effectively.

Experiments were designed to:

1. Compare farmers' implementation of frijol espeque practices in terms of the effects of crop and land management practices on yields, economic returns, soil nutrients, and soil losses due to erosion.
2. Compare the effects of land use intensification on yields and soil degradation for frijol tapado, labranza cero, and clear-field planted frijol espeque practices.

Throughout this series of agronomic experiments the following questions were being addressed:

1. What are the trade-offs between decreased soil degradation and increased yields?
2. What is the relationship between maximal yields and maximum profitability?
3. Which components of each technology affect its sustainability or its ability to be adopted by resource-poor farmers?

The integrated investigation of agronomic and socioeconomic factors permits both a critical evaluation of existing technologies and the recommendation of alternative technologies to increase the sustainability of bean production on steep slopes.

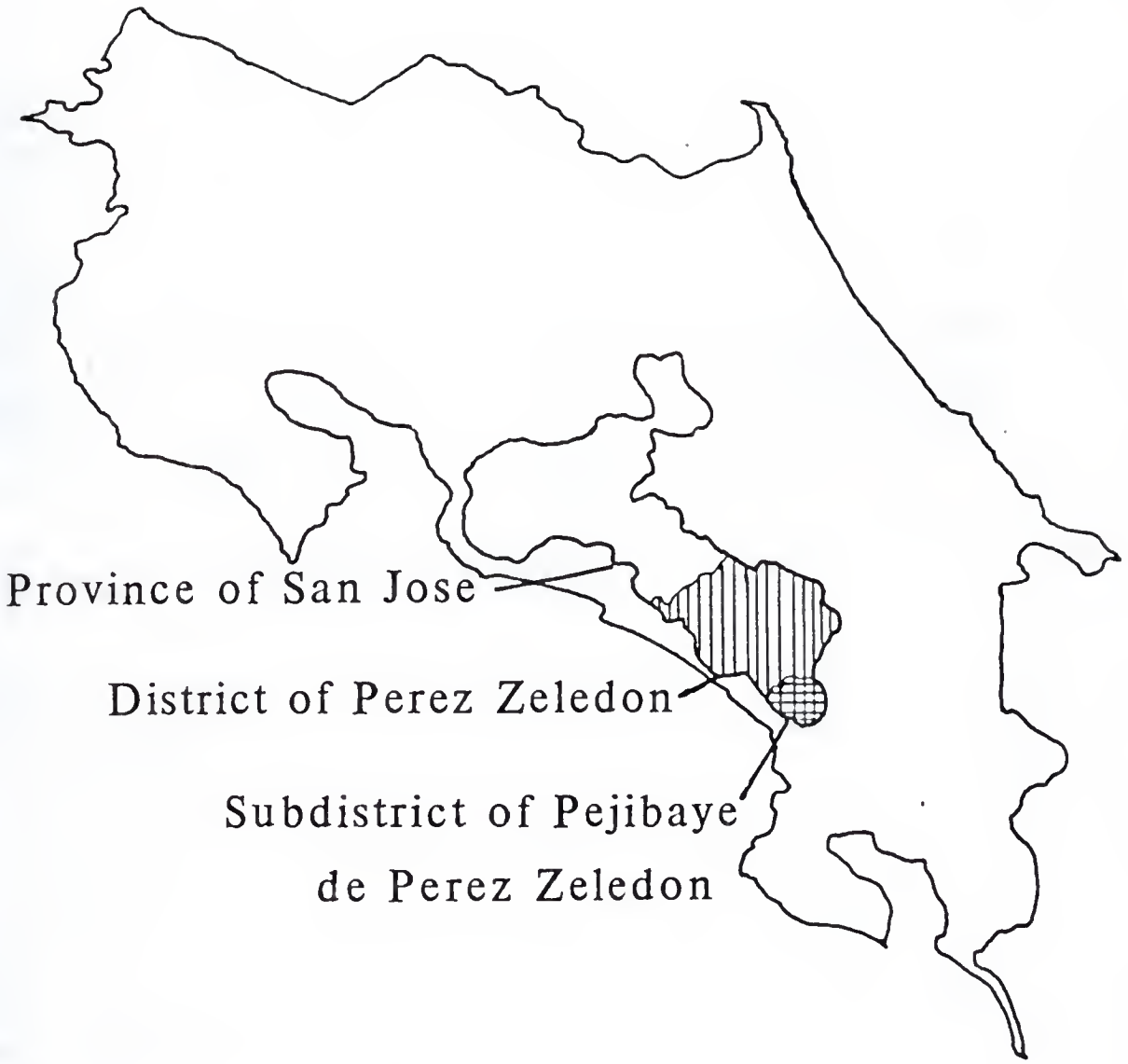


Figure 2.1: The location of Pejibaye de Peréz Zeledón.

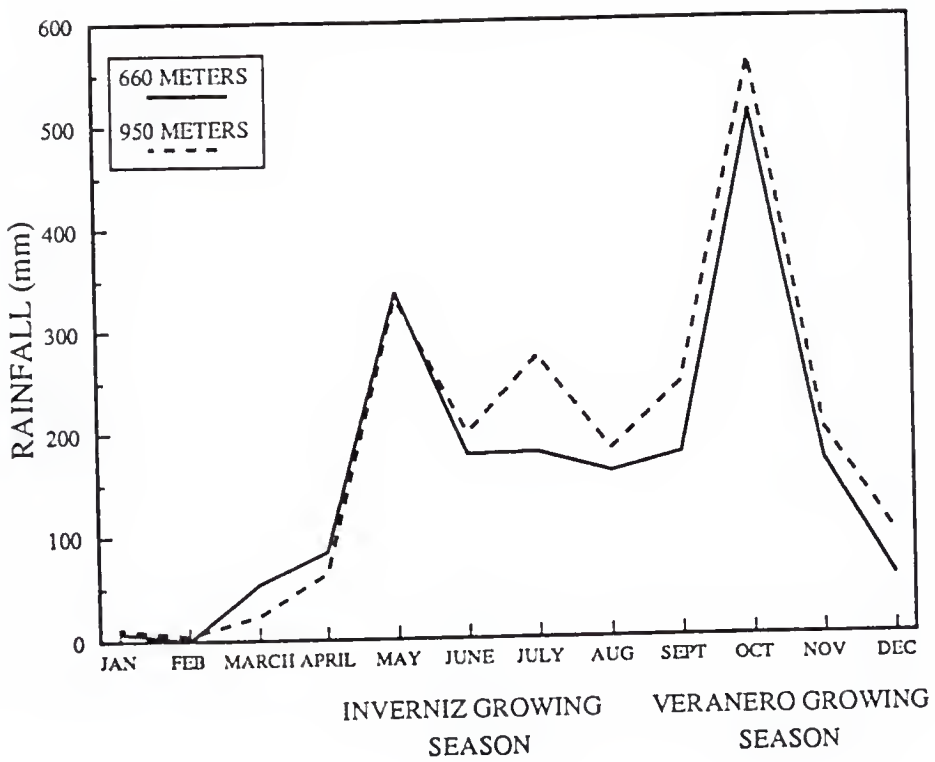


Figure 2.2: Rainfall for 1990 at two elevations in Pejibaye de Peréz Zeledón. Source: Instituto Costarricense de Electricidad (1991)

Figure 2.3: Deforestation of Pejibaye de Peréz Zeledón-1973.
Source: Instituto Nacional Geografico.

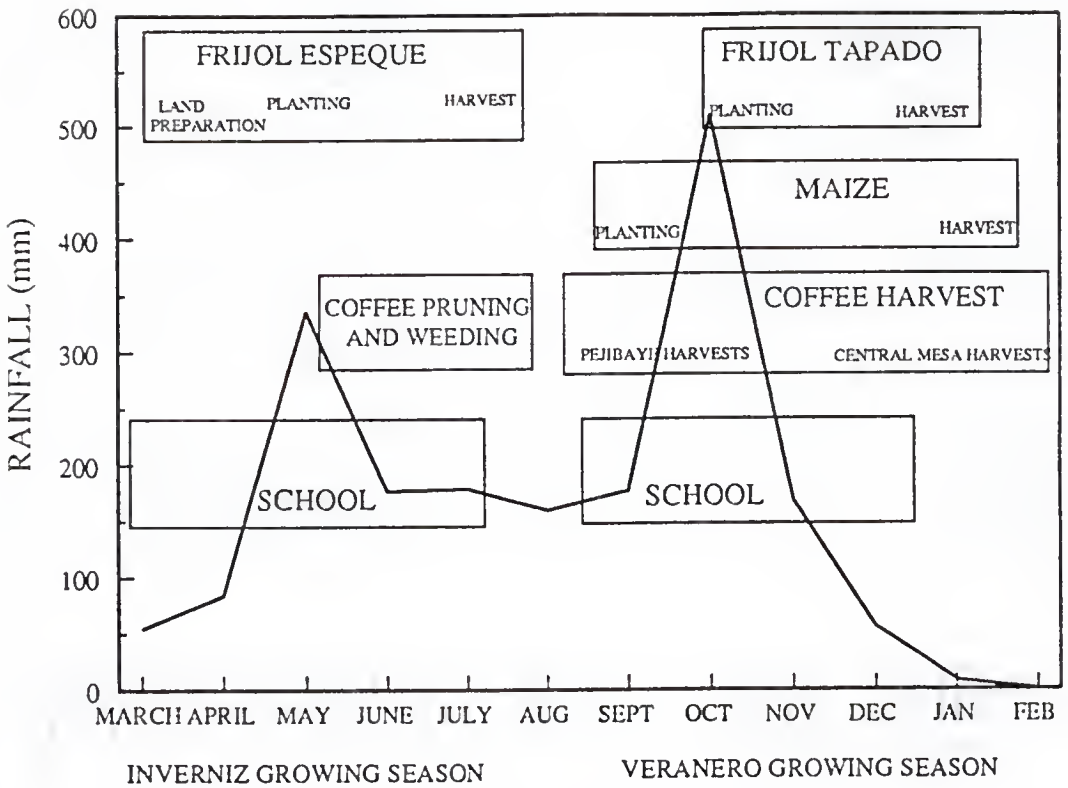


Figure 2.4: Calendar of agricultural activities and school semesters in Pejíbaye de Peréz Zeledón in relationship to rainfall.

Tora (Verbesina sublata)

Guarumo (Cecropia spp.)

A typical nine month fallow with plantanilla (Heliconia spp.) and jaragua (Hypahenia rufa) predominating

A typical woody two to three year fallow used for frijol tapado production

Figure 2.5: Common plants and plant associations found in frijol tapado fallows.

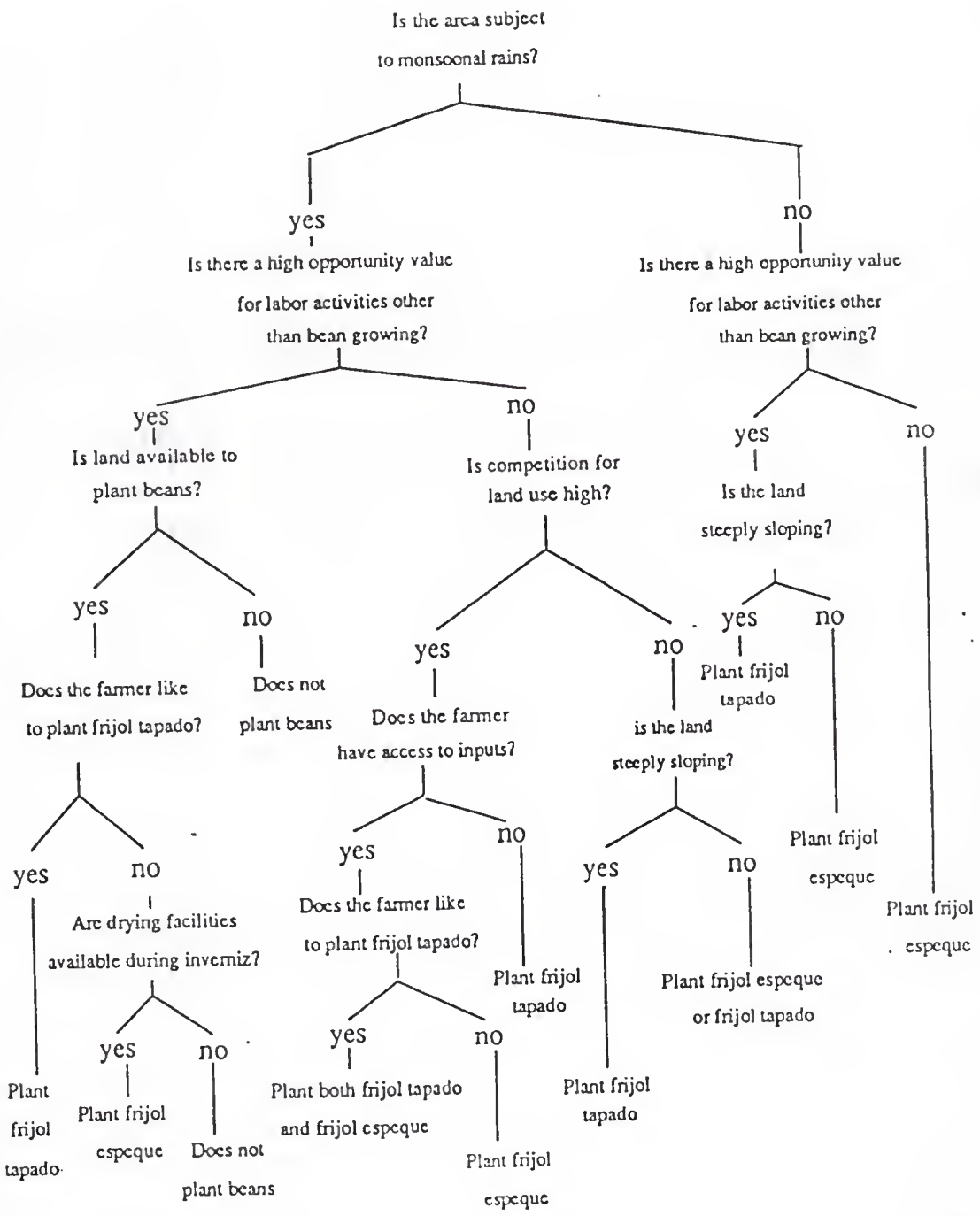


Figure 2.6: Frijol tapado and frijol espeque decision tree.

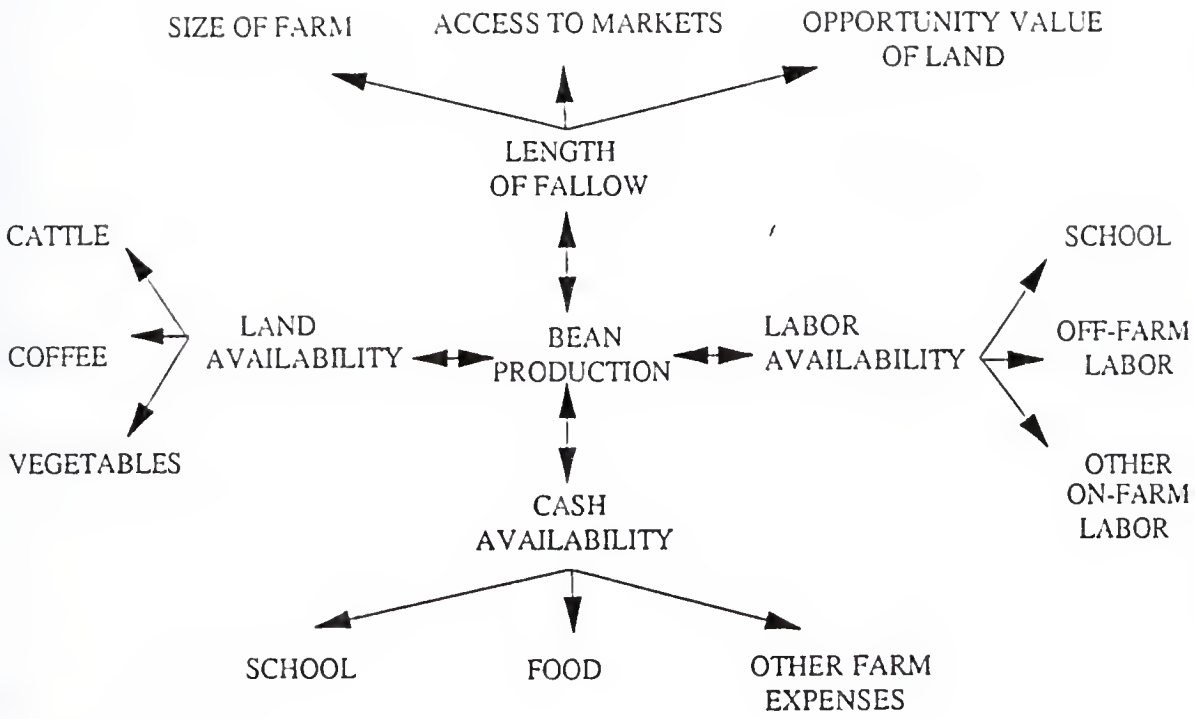


Figure 2.7: Socioeconomic interactions affecting the sustainability of bean production.

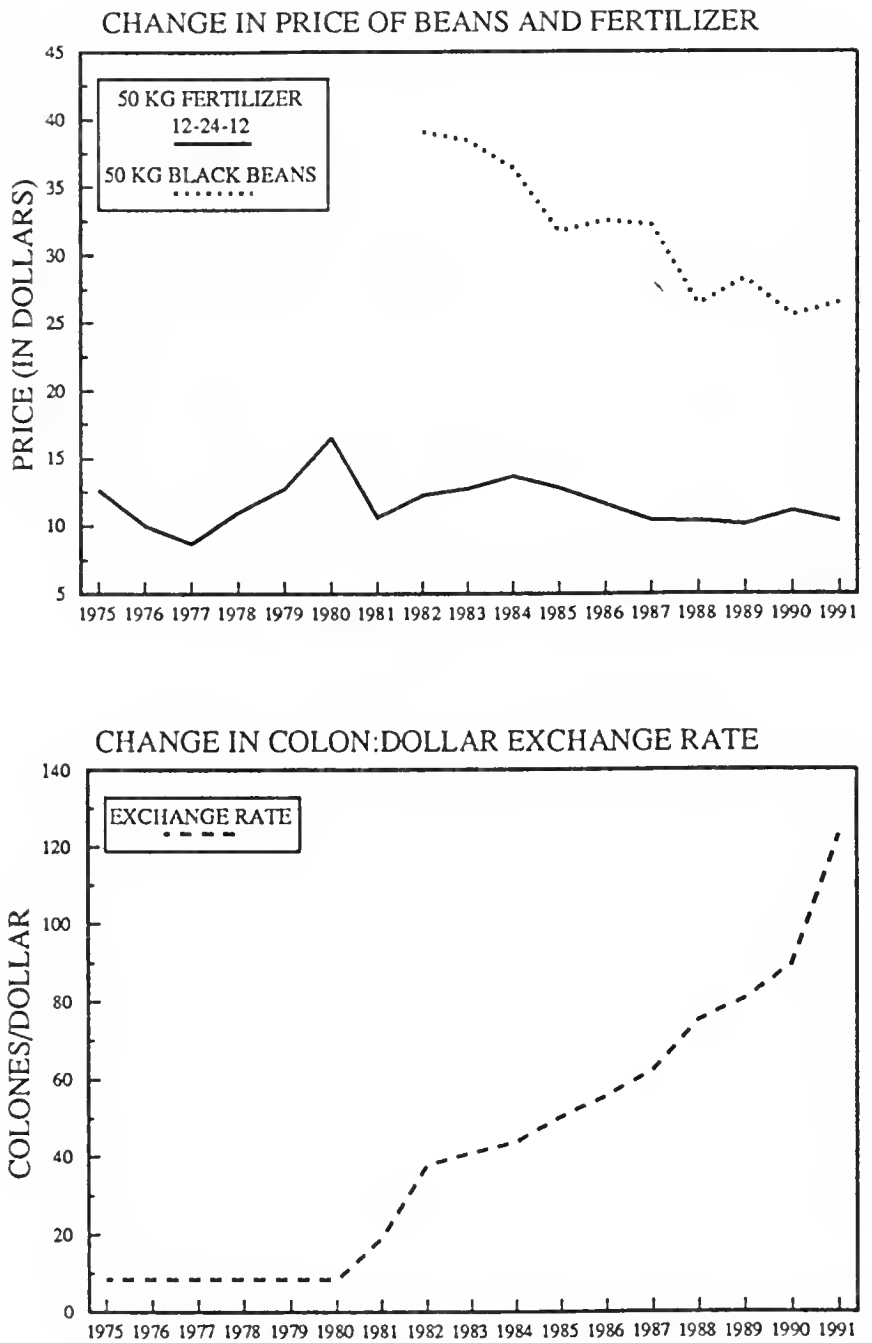


Figure 2.8: Changes in the prices of beans and fertilizer and in the colon:dollar exchange rate: 1975-1991.

Table 2.1: Summary of surveys conducted.

Survey	Location	Participants	Time
Introductory survey (Appendix A)	Pejibaye de Pérez Zeledón	51 steep-land bean growing farmers including: 18 tenants 33 farmer-landowners	March-April 1990
Frijol espeque economic survey (Appendix B)	Pejibaye de Pérez Zeledón	31 frijol espeque farmers including: 19 tenants 12 farmer-landowners	June-August 1990
Frijol tapado: economic survey (Appendix C)	Pejibaye de Pérez Zeledón	15 tenants and 9 farmer-landowners	December 1990-January 1991
Frijol tapado: practices in remote areas (Appendix C)	Guagural de Bueños Aires and San Vito de Coto Brus	33 frijol tapado farmers	July 1991
Informal surveys	Pejibaye de Pérez Zeledón, San Vito de Coto Brus and San José	tenants landlords input dealers MAG and CNP extension agents UCR professors	March 1990-August 1991

Table 2.2: Characterization of tenants and farmer-landowners in Pejibaye de Pérez Zeledón.

TENANTS (n=18)		LANDOWNERS (n=33)	
Tenancy Agreements:	(%)	Landholdings:	(%)
Halves	29	0-3.0 ha	16
Thirds	71	3.1-7.0 ha	28
Length of Tenancy:		7.1-16.0 ha	25
< 2 years	33	16.1-35.0 ha	25
2-5 years	53	> 35 ha	6
> 5 years	9		
Size of Bean Field:	(%)	Size of Bean Field:	(%)
0-1.4 ha	39	0-1.4 ha	24
1.5-3.0 ha	39	1.5-3.0 ha	48
3.1-5.0 ha	22	3.1-5.0 ha	18
> 5.1 ha	0	> 5.1 ha	9
Other Economic Activities:	(%)	Other Agricultural Products:	(%)
Maize production	100	Maize	100
Coffee production	28	Coffee	85
Coffee harvests	88	Cattle	64
Hired Laborer	65		

Table 2.3: Input use in frijol espeque and frijol tapado.

	TENANTS		LANDOWNERS	
	FRIJOL ESPEQUE (% use)	FRIJOL TAPADO (% use)	FRIJOL ESPEQUE (% use)	FRIJOL TAPADO (% use)
USE OF EACH BEAN PLANTING METHOD				
by tenancy	35	39	65	61
by planting method	100	50	100	42
SEED VARIETIES USED				
Certified Seeds	0	0	18	0
Introduced	44	44	67	37
Traditional	17	37	19	37
Mixture	39	19	13	25
AGROCHEMICAL USE				
Herbicides	100	0	100	0
Fertilizers	33	0	83	0
Molluscacides	33	38	54	33
Insecticides	14	0	25	0
Fungicides	28	0	42	0
HIRED LABOR USE	80	47	25	12

Table 2.4: Plant species commonly found in frijol tapado fallows.

Local Name	Species	Family
TREES (FALLOWS OF 2 OR MORE YEARS):		
guavo	Inga spp.	Mimosaceae
chaperno	Calliandra spp.	Leguminosae
madera negra	Gliricidia sepium	Leguminosae
guarumo	Cecropia spp.	Moraceae
jobo	Spondias mombin	Anacardiaceae
targua	Croton spp.	Euphorbiaceae
achiotillo	Vismia guianensis	Guttiferae
varnilla negro	Cordia palycephala	Boraginaceae
SHRUBS (FALLOWS OR 1-2 YEARS):		
tora	Verbesina sublata	Compositae
tuete	Veronia vernicosa	Compositae
paira	Melanthera aspera	Compositae
moriseco	Bidens pilosa	Compositae
churrite	Priva aspera	Verbenaceae
mastuerzo	Scoparia dulcis	Scrophulariaceae
navajuala	Scleria secans	Cyperaceae
helecho	Pteridium aquilinum	Pteridaceae
plantanilla	Heliconia spp.	Musaceae
churristate	Ipomoea spp.	Convolvulaceae
GRASSES (FALLOWS OF 1-2 YEARS):		
jaragua	Hypahenia rufa	Gramineae
calinguero	Melinin minutiflora	Gramineae
tarquesa	Imperata contracta	Gramineae
zacate peludo	Paspalum paniculatum	Gramineae
zacate fuego	Rottboellia exaltata	Gramineae
abrojo	Cenchrus brownei	Gramineae

Sources for scientific names: Pittier (1957) and Araya and González, (1987).

Table 2.5: Comparisons of frijol tapado production systems: Pejibaye and San Vito/Guagural

	PEJIBAYE: % of respondents (n=23)	SAN VITO / GUAGURAL % of respondents (n=21)
Length of fallow used for frijol tapado production:		
9 month (annual production)	33	41
2 years	24	33
3 years or more	20	26
2 + years with concurent pasture use	23	nr[a]
Use of land following frijol tapado production:		
9 month fallow/frijol tapado	33	41
2 + year fallow/frijol tapado	5	20
Frijol espeque/maize/fallow/frijol tapado	0	39
Frijol espeque (continuous cultivation)	43	0
Pasture	11	0
Coffee	8	0
Seed varieties used:		
Traditional varieties	39	46
Introduced varieties	44	8
Combination of traditonal and introduced varieties	17	46
Use of frijol tapado yields for sale:	50	85

a. No response: not included in questionaire.

Table 2.6: Economic aspects of frijol espeque and frijol tapado.

	Tenants		Landowners	
	Frijol Espeque (n=19)	Frijol Tapado (n=15)	Frijol Espeque (n=12)	Frijol Tapado (n=9)
Seed planted (kg ha^{-1})	24	29	27	31
Jornales[a] of family labor	35	22	34	25
Jornales of hired labor	8**	4	4	1
Total jornales of labor	43	26	38	27
Commercial input costs[b]	7161**	1502	7238**∞	1672
Labor costs	2882**	1274	1292	500
Total costs	10042**°	2776	8531*	2172
Yield (kg ha^{-1})	507**	210	833**	284
kg harvested/kg planted	22**	7	33**	10
Gross income[c]	25364**	10480	41654**	14194
Rent[d] / land payments	8446**	3488	2000	2000
Net income	6850**	4203	31123**∞	10021∞
Gross income/costs	1.47	1.67	3.95∞	3.40∞
Net income/ costs	1.38	1.94	2.95°	2.40°
Net income/jornal	232	280	819∞	371

a. A jornal is a 6 hour farm labor day valued at 350 colones.
b. All economic values are in colones (107 colones=$1, 1-1-91).
c. Bean yields were valued at 50 colones/kilogram.
d. One third of the crop harvested.

Significant difference between frijol espeque and frijol tapado at the F=0.01 and 0.05 levels are indicated by ** and *, respectively. Significant differences between tenants and landowners at the F=0.01 and 0.05 levels are indicated by ∞ and °, respectively.

CHAPTER 3
BEAN GROWING ON STEEP LANDS: RELATIONSHIPS BETWEEN LAND USE, BEAN YIELDS, AND SUSTAINABILITY

Sustainability of Introduced Technologies

Frijol espeque practices were introduced to allow farmers to use their land more intensively, to employ crop management practices more effectively, and to obtain higher yields. In the area of Pejibaye de Pérez Zeledón, favorable climatic conditions, combined with accessibility to markets and targeted extension programs, resulted in high levels of adoption of introduced seed varieties (Chapman et al., 1983; Pachico and Borbón, 1987a). In conjunction with the adoption of introduced varieties, most farmers in this area also adopted the frijol espeque planting method.

Recommendations for planting frijol espeque included use of certified seeds, herbicides, fertilizer, fungicides, and insecticides. Farmers planting beans on steep lands have not adopted frijol espeque recommendations completely. The incomplete adoption of extension recommendations was due primarily to economic constraints rather than to a lack of information. High rental costs and short-term tenancy agreements discouraged tenants from either investing in agrochemical inputs or adopting land-conserving farming practices. Investments in agrochemicals competed with household and school expenses for the scarce economic resources of the farm family. Small-scale landholders were

constrained from placing land into a regular fallow rotation by the need to maximize production on their limited land.

According to farmers, the profitability of bean farming has decreased due to degrading environmental conditions as well due to as economic conditions. Many noted that, despite applying more inputs, they were obtaining lower yields. Soil degradation due to intensified land use and erosion may be limiting the yields obtained by higher-input agricultural practices.

While continuing to promote the adoption of frijol espeque, extension workers have recognized the potential for soil degradation associated with this practice (Barrantes et al., 1986). Consequently, extension agents are currently recommending to farmers that they adopt *labranza cero* practices. Labranza cero differs from current practices in that crop residues are neither removed nor burned. Instead, residues are cut and left in place on the soil surface. Regrowth of cut residues is controlled by the application of preplant, burn-down herbicides at planting.

Although labranza cero may increase the long-term production potential of the field by slowing processes of soil degradation, the presence of residues on the soil surface may favor crop losses due to slug infestations. Tapia and Camacho (1988) stressed the importance of controlling slug populations prior to their establishment in labranza cero fields. According to farmers, the limiting factor for the adoption of labranza cero is the time constraint for planting fields during the optimal period. They felt that they would need to decrease the land planted by 25% to 50% if they were to

adopt labranza cero. Thus, despite interest in adopting more sustainable farming methods, the benefits of adopting labranza cero may not outweigh the risks of adoption.

Soil Degradation

Soil Erosion

Existing frijol espeque practices potentially promote soil degradation due to erosion. Erosion degrades soil resources through the removal of topsoil and organic matter. On steeply sloping lands with shallow topsoils and poorly developed subsoils, soil losses due to erosion may lead to an irreversible decline in soil productivity (Lal, 1985).

Due to its low bulk density, organic matter is preferentially removed during erosion (Lal, 1987a). Loss of organic matter results in chemical, physical, and biological soil degradation. For highly weathered tropical soils, loss of organic matter will result in a decrease in the effective cation exchange capacity (ECEC) (Logan, 1990). Decreased soil organic matter is also associated with increased soil bulk density, decreased water holding capacity (Shaxson, 1985) and decreased aggregate stability (Chaney and Swift, 1984). Loss of organic matter, furthermore, disrupts microbial growth and nutrient cycles (Sims, 1990).

Soil erosion is a function of rainfall erosivity, soil erodibility, topography, crop management, and soil conservation (Hudson, 1976). Rainfall erosivity is the force causing soil detachment and transport (Lal, 1988). It is related to the kinetic energy of raindrop impact and water runoff. Erosivity can be assessed indirectly, based on rainfall

amounts and intensity. On southern African soils, Hudson (1976) obtained a threshold value for rainfall intensity of 25 cm hr^{-1}. Erosion occurred at rainfall intensities higher than the threshold values. At lower rainfall intensities, soil erosion was negligible.

Soil erodibility is a measure of the resistance of soil to particle detachment (Lal, 1988). It is related to soil clay and organic matter content (Lal, 1988), particle dispersion (Middleton, 1930), and soil aggregation (Bryan, 1968). Increased soil aggregation was associated with increasing lengths of fallow (Elliott, 1986; Wadsworth et al., 1988). Soil erodibility was reduced during the first year of cultivation following grass fallows of one to two years (Hudson, 1976). Jastrow and Miller (1990) suggested that fine roots and mycorrhizae may be responsible for the formation of aggregates during fallow. In addition, the formation of microbial metabolites, including lipids, proteins, phenols, and extracellular polysaccharides, is associated with the stabilization of soil aggregates (Burns and Davies, 1986).

Slope length and steepness affect the overland flow of water responsible for sheet and rill erosion. Particle detachment by raindrop splash and overland flow velocities are greater on steep slopes than on shallow slopes (Lindsey and Gumbs, 1982). Longer slopes also permit an increasing velocity of surface run-off (Hudson, 1976). Studies by Moore and Burch (1986) indicated that, as slopes become steeper and longer, sheet flow is transformed into rill flow. McCool et al. (1989) recommended that run-off plots have a slope length of at least four meters in order to initiate rill flow on recently disturbed soils. Calculations by Rose (1988) indicated that soil loss increased exponentially as slope length increased from six to ten meters. Soil losses from slope lengths of seven

meters were 50% of the soil losses from slope lengths of 40 meters, while a ten meter slope length produced 90% of the soil losses obtained from the 40 meter plot.

Lal (1984b) reported an interaction between slope length and steepness for Nigerian Alfisols. On slopes with less than 5%, slope length has little effect on erosion. On slopes of 15%, slope lengths of 10 meters and 15 meters resulted in 64% and 75%, respectively, of the annual soil loss per hectare obtained from plots with a slope length of 20 meters.

Crop management and mulching affect soil coverage. Soil coverage by plant canopies and mulches protects soil from erosion by absorbing the kinetic energy of raindrop impact. Mulches having a close contact with the soil further reduce erosion by reducing the velocity of runoff (Wischmeier, 1975). The relationship between soil erosion and soil cover is curvilinear; a soil cover of 60% protects the soil almost as much as a soil cover of 100% (Stocking, 1988). In studies involving laboratory test plots and simulated rainstorms, Lattanzi et al. (1974) reported reductions in interrill erosion of 40% when 0.5 tons ha^{-1} of mulch were applied. Soil losses were further reduced by 80% when mulching rates were equivalent to 2 tons ha^{-1}. At mulching rates of 8 tons ha^{-1}, soil erosion was negligible. On field plots five meters in length, on a tropical Alfisol, mulching rates of 2, 4, and 6 tons ha^{-1} had cumulative soil erosion of 20%, 5% and 1%, respectively, of a corresponding bare plot. No soil or water runoff was obtained from plots with mulch rates of 12 tons ha^{-1} (Lal et al., 1980).

Canopy cover can reduce erosion by intercepting the impact of raindrops. For partial canopies, erosion is proportional to the percentage of the ground not covered by

the canopy (Wischmeier, 1975). Increased plant vigor, causing rapid plant growth and development, decreases erosion due to rapid canopy cover. In erosion-control trials, fertilization of cassava fields not only increased yields dramatically, but also decreased erosion due to the more rapid growth and soil cover (CIAT, 1985).

Intensity of Land Use

The transition from crop-fallow to continuous cropping systems causes soil nutrient losses due to land clearing and harvest. When nutrient losses from the system are not replaced by nutrient inputs, a net loss of nutrients occurs. When fallowed areas are cleared for agricultural production, a decline in soil carbon and nitrogen levels occurs due to increased rates of mineralization (Greenland and Nye, 1959; Wadsworth et al., 1988). Juo and Lal (1977) reported rapid decreases in organic matter and pH levels in continuously cropped, unmulched, maize and soybean fields. By applying 16 metric tons ha^{-1} of mulch annually, organic matter levels comparable to fallow treatments were maintained in these fields.

Cations are poorly retained by highly weathered tropical soils due to the low ECEC of these soils. Under the natural forest ecosystem, nutrients are retained in the system due to the presence of an active root mat (Jordan and Herrera, 1981). In cultivated systems, a developed root mat is absent from the time of land clearing through early plant growth stages. This lack of a developed root mat allows plant nutrients to leach readily through the soil profile. The cutting, drying, and burning of a Costa Rican forest resulted in the loss of over 60% of the potassium from the plant biomass, due to

leaching (Ewel et al., 1981). Swift (1985) recommended the application of slowly decomposing litter to soils to help conserve plant nutrients through short-term immobilization.

Land fallowing can be used to regenerate soil nutrients and organic matter. Organic carbon levels in soils are directly related to fallow length (Ramakrishnan, 1988; Wadsworth et al., 1988). Soil carbon was depleted from slash-and-burn rotations in India when cropping cycles were alternated with fallows of 5 years or less in length. Soil carbon attained maximum levels after 10 years of fallow, while phosphorus concentrations increased with fallow length for up to 30 years (Ramakrishnan and Toky, 1981).

Burning of Residues

Fire is used in slash-and-burn agricultural systems to clear the land and to provide readily accessible nutrients for plant growth. Fire may also be used to kill weeds and invertebrate pests. Although fire can provide short-term increases in crop yields, it can also result in rapid losses of nutrients due to leaching or runoff. Fire can also degrade soil physical properties.

During a burn, cations in the fallow biomass are released in the form of ash. This process increases the availability of cations for plant uptake and the pH of the surface soil. Although burning causes a more rapid release of nutrients compared to decomposition, loss of nutrients is also high when residues are burned. Following forest burning, 40% of the calcium and magnesium in all above- and below-ground biomass

were lost due to leaching (Ewel et al., 1981). Burn intensity also affects nutrient availability from residues. High-temperature burns (>400° C) volatilized all biomass carbon and nitrogen and reduced soil CEC (Ewel et al., 1981). In incomplete burns, CEC was increased and organic carbon, nitrogen, and phosphorus were added to the soil as partially decomposed residues (Andriesse and Schelhass, 1987a).

The removal of canopy and mulch cover through burning enhances the susceptibility of the soil to erosion. On sloping lands, nutrients in the ash may also be lost through runoff. Additionally, the heat of burning may increase the erodibility of the soil due to the formation of hydrophobic and cementing substances on soil aggregates (Giovannini et al., 1987).

Consequences of Soil Degradation

Erosion, short fallows, and residue burning causes a depletion of soil nutrients and organic matter. Soil organic matter depletion is related to decreased aggregate stability, decreased water infiltration, decreased water-holding capacity, a breakdown of microbially mediated nutrient cycles, and increased soil bulk density. Soil degradation lowers soil productivity. Lal (1981) obtained exponentially decreasing grain yields with linearly increasing cumulative erosion.

Soil degradation not only affects crop growth but also weed growth and successional processes occurring during fallow regrowth. Species diversity is less during the early stages of succession, and then increases with successional maturity (Odum, 1975). Decreasing diversity within hillside agricultural systems was shown to be related to decreasing sustainability of the agroecosystem (Jodha, 1990).

Field Assessment of the Effect of Technology Change on Soil Degradation

Study Design

The farming systems approach is based on the premise that by integrating farmers into agricultural research and extension activities, recommendations developed will be more readily adopted. Although agricultural scientists are included as members of multidisciplinary development teams, sondeos and rapid rural appraisal methods usually are more effective in eliciting socioeconomic rather than agronomic information. Field observations are often given second priority to farmer interviews. When field observations are conducted in conjunction with farmer interviews, they may provide limited information. Agronomic data from sondeos is often limited to farmer descriptions of agricultural systems or static observations of agricultural practices. The collection of agronomic data may be hindered further when interviews are scheduled for periods between cropping seasons.

To obtain detailed agronomic data about the agroecosystem, Rhoades (quoted by Chambers and Ghildyal, 1985) recommended using a flexible approach to program development. Experiments may be conducted early in project development in order to identify problems. Similarly, the Diagnosis and Design (D & D) methodology developed by International Centre for Research in Agroforestry (ICRAF) incorporates a reiterative approach to problem identification and research design (Raintree, 1987). Although these approaches provide useful information for program development, the implementation of experiments prior to diagnosis is problematic. The premature identification of treatments

indicates that constraints were assumed to be known, and potential treatments identified, prior to conducting farmer surveys (Sumberg and Okali, 1988; Chambers and Jiggins, 1987a).

In the implementation of on-farm experiments, introduced technologies are tested against "farmer practices." The farmer practices, however, usually do not represent a single farming practice. Instead, these practices vary due to environmental conditions, farmer access to resources, or indigenous farmer knowledge. By treating these practices as a single treatment, the variability of the indigenous practices is not acknowledged. By using research designs that do not assess differences between farmer practices, researchers are prevented from identifying potentially useful indigenous practices. As a result, recommended practices may need to undergo a process of farmer adaptation before high levels of technology adoption occur (Rhoades and Booth, 1982; Horton, 1986).

Alternatively, diagnostic surveys can be designed to include more agronomic variables. Byerlee and Triomphe (1991, as cited in Eilitta et al., 1991) argued that researchers can better understand farmers' management practices and analyze factors causing variation and loss of yield through the inclusion of agronomic variables in farm surveys. Agronomic variables suggested by Byerlee and Triomphe (1991) included soil characteristics, topography, crop management practices, and environmental factors including nutrient deficiency symptoms and pest and weed infestations. Erosion potential can be assessed through measurements of land slope, soil coverage, and rainfall (Stocking and Abel, 1980). The effect of environmental and management factors on yield can be

assessed statistically using correlations and stepwise regression procedures (Eilitta et al., 1991).

Assessment of Agronomic Variables

The potential for soil degradation can be assessed by monitoring the factors affecting soil erosion; rainfall intensity, cropland topography, the use of fallow rotations, and the percentage of soil coverage. Runoff plots can be used to assess the effect of different crop management or conservation practices on erosion losses. Measurements of runoff taken during a single growing season, however, provide only a static indication of soil losses. To assess the effect of losses on soil degradation, soil physical, chemical, and biological properties affected by loss processes should also be monitored. Degradation due to erosion and increased land-use intensity can be assessed based on measurements of organic matter, soil pH, aluminum saturation, bulk density, aggregate stability, microbial biomass, and symbiotic associations of plants with rhizobia or mycorrhizae. In order to estimate the effect of changes over time, measurements from degraded areas should be assessed in relation to undisturbed or recently disturbed areas. In addition to assessing soil degradation directly, the indirect effects of soil degradation should be assessed. The indirect effects include weed infestation, disease incidence, crop yields, and the profitability of crop production.

To determine the environmental sustainability of current frijol espeque practices, an assessment of current farmer practices was conducted from April to July of 1990. The effects of residue burning, land fallowing, and labranza cero practices on enhancing or decreasing bean yields and soil degradation were examined. The studies did not

involve imposed treatments. Instead, analyses were designed to determine correlations between crop yields and soil, environmental, and farm management practices. Relationships between soil properties and bean growth as a function of land management practices were also assessed.

Materials and Methods

Field Analyses

Selection of farms. Based on results from responses to the farmer interviews, 12 frijol espeque farms were selected for detailed environmental studies. The locations of the farms used in this study are shown in Figure 3.1. The 12 farms were chosen to include four land management practices; labranza cero, residue burning, continuous cultivation, and land fallowing. All fields studied had slopes greater than 50%. The directional aspect, slope, prior land use, and residue management practice of each farm included in the study are shown in Table 3.1.

Erosion assessments. To assess erosion potential, the percent slope was measured using a clinometer. Soil coverage by mulches was determined by collecting all plant residues within randomly selected 0.125 meter square quadrants. Residues were collected, dried and weighed. Assessments were made in triplicate at the time of planting. Rainfall amount and intensity were monitored throughout the growing season.

In each field, a modified erosion runoff plot (Mutchler et al., 1988), 10 meters x 3 meters in size, was installed. The horizontal sides of the runoff plots were constructed of heavy-duty plastic sheeting. The edges of the plastic were embedded and

nailed into the soil. Strips of sheet-metal were embedded into the soil to protect against soil and water inflow from above the plot. The collection troughs, constructed of plastic sheeting, had a capacity of approximately 200 liters. Runoff plots were installed between May 10 and May 16. The soil accumulated in troughs at the base of the runoff plot was collected and weighed four times during the bean growing season; at one week, three weeks, six weeks, and ten weeks after planting. Representative soil samples from the runoff plots were air-dried, ground to pass through a 100-mesh sieve, and analyzed for available P, K, Ca, and Mg using a 4:1 (v/w) ratio with Mehlich I extractant (Mehlich, 1984). Organic carbon was analyzed according to the Walkley-Black procedure (Nelson and Sommers, 1982). Soil pH was assessed using a 2:1 water:soil paste.

Rhizobia nodulation of bean roots. At four, five, and seven weeks after planting, eight hills of bean plants were randomly selected from each farm. The roots were carefully removed from the soil and nodulation was evaluated based on abundance, size, and color of the nodules (CIAT, 1988b). Due to differences in planting times and bean varieties used, nodulation differences between fields were compared based on maximum nodulation recorded in each field independent of sampling time.

Soil chemical analyses. In each field, duplicate, bulked soil samples were taken at the time of planting and at the time of harvest. Each bulked soil sample consisted of 20 subsamples taken to 15 cm. The subsamples were taken along a vertical transect 20 meters long, from five meters below the base of the runoff plot to five meters above the upper end of the runoff plot. Soil samples were air-dried, ground to pass a 100-mesh

sieve, and analyzed for available P, K, Ca, and Mg, organic carbon, and pH using the methods described above.

Microbial biomass assessments. At the time of harvest, sub-samples of the bulked soil samples, maintained under refrigeration, were transported to San José for nitrate and microbial biomass analyses. Analyses were conducted within three days after sampling. Soil nitrate was extracted using a 10:1 ratio of 1 N KCl to fresh soil. Nitrate analyses were performed using a Technicon AutoAnalyzer (Technicon, 1978). Microbial biomass ammonium was assessed using a modification of the fumigation-extraction method described by Sparling and West (1988). Twenty grams of fresh soil were subjected to an 18 hour chloroform fumigation within a desiccator jar. After flushing the desiccator, soils were immediately extracted with 100 ml of 1 N KCl. Ammonia in fumigated and nonfumigated extracts was assessed using a Technicon AutoAnalyzer (Technicon, 1977).

Harvest analyses. Bean yields from experimental plots were determined based on the dry weight of beans collected within 3 m^2 quadrants. For each field, assessments were conducted in triplicate. Bean plants collected within the same quadrants were separated into stems, leaves, pods, and seeds. Each portion was dried and weighed. Sub-samples taken from each sample portion were ground using a Wiley mill and analyzed for N using the Kjeldahl digestion method (Bremner and Mulvaney, 1982). Plant tissues were assessed for K and for P using a Technicon AutoAnalyzer following dry ashing and dissolution in 10 N HCl.

Pest infestation and farm management practices. Relative weed incidence was assessed four times during the growing season and at harvest. Web blight was assessed

based on the percentage of plants affected. Weed incidence was based on the percentage of randomly selected rows that exhibited weed growth.

In addition, all farmer inputs of manual labor, fertilizers, and pesticides were monitored and recorded through detailed farmer interviews.

Statistical Analysis

Environmental and management parameters assessed were regressed individually and additively against yields using the regression procedure of the statistical package SAS (SAS, 1985). Farms included in the study were segregated, independently, as belonging to, or not belonging to, three categories of land-use: labranza cero, burned-field, or fallowed field. Farms belonging to each category were tested against farms not belonging to that category using the t-test procedure (SAS, 1985). Factors assessed in t-test analyses included yields, net returns, and soil data.

Results and Discussion

Rainfall

Rainfall during the three-month growing season was 486 mm. Six rainfall events had intensities of 20 mm or more per hour. Rainfall, bean production activities, and sampling times are shown in Figure 3.2.

Variability Among Farms

All farms included in this study were located within seven kilometers of the commercial center of Pejibaye, were managed by landowners, and were planted using

the frijol espeque method. Despite these similarities, these fields did not represent a single "farmer practice." Instead, distinct differences in field preparation and crop management practices were observed. These practices affected both yields and the degradation of soil resources.

The variability in soil characteristics and management practices among farms included in the study was high (Tables 3.2, 3.3). Farm management practices are summarized in Table 3.2. Values obtained at planting for soil nutrients, pH and organic matter are given in Table 3.3. Values obtained for erosion, weed and web blight incidence, rhizobia nodulation, microbial biomass, and nutrient uptake also exhibited a wide range of variability among farms (Tables 3.4, 3.5). Yields ranged from 157 to 1372 kg ha^{-1}, while erosion losses ranged from negligible to more than 8 tons ha^{-1}. Similarly, web blight and weed incidence ranged from negligible to almost total. The high variability in environmental and management factors also resulted in high variability among economic factors (Table 3.6).

Parameters of Sustainability

Three factors indicative of high soil fertility: soil organic matter, soil cations, and microbial biomass, had significant relationships when individually regressed against yields (Table 3.7). None of the environmental and farm management variables assessed produced significant relationships when regressed against net returns (Table 3.8). No combination of variables tested produce a significant relationship with net returns. Yields were not significantly related to either input expenses or labor inputs.

A combination of microbial biomass and soil organic matter accounted for over one-half of the variability in yields (Table 3.9). Microbial biomass is an early indicator of increasing levels of soil organic matter and nitrogen availability in the soil (Ayanaba et al., 1976; Lynch and Panting, 1980; Powlson et al., 1987).

Although overall yields were significantly related to high soil organic matter levels, assessments of the land-use practices were inconclusive in indicating methods for enhancing or maintaining soil organic matter levels. None of the land-use practices studied were related to significantly higher levels of organic matter (Table 3.10 and 3.11). Fallows used during frijol espeque production are typically no longer than three years. This length of fallow is insufficient to regenerate organic matter levels of the soil (Wadsworth et al., 1988). The mulch application levels used for labranza cero fields were less than 2 tons ha^{-1}. This is only 13% of the rate used by Juo and Lal (1977) to stabilize soil organic matter at levels similar to that from long-term fallows.

Parameters of Degradation

Significant relationships between soil degradation and decreased bean yields was obtained in these studies. Soil losses due to erosion and web blight incidence had significant and inverse relationships when regressed against yields (Tables 3.7 and 3.9).

Weed incidence. All farmers used paraquat herbicides at the time of planting and hand-weeded their fields at least once during the growing season. Despite the use of weed control practices, weed incidence was high in almost all fields. Due to two outlying points, representing farmers who weeded their fields twice, the relationship

obtained between weed incidence and yields was low (Table 3.7). Almost 70% of the variability in yield was accounted for when weed incidence was combined with web blight incidence and soil erosion (Table 3.9).

Decreased soil fertility and increased intensity of agricultural activities increases weed populations and decreases plant diversity (Kellman, 1980). In shifting agricultural practices, abandonment of fields is usually due to a combination of decreasing fertility and increasing weed incidence (Harcombe, 1980). Wade and Sanchez (1983) indicated that weed competition is a major obstacle to increasing agricultural intensity in the Amazon Basin.

Soil erosion. Soil losses due to erosion were significantly and inversely related to yields (Table 3.7). Nutrient removals due to erosion decrease the availability of nutrients for plant uptake. The percentage of organic matter in runoff averaged over one-and-one-half times the organic matter percentage of the bulk soil. Fields that had been subject to more than two years of continuous cultivation exhibited highest losses of organic matter due to erosion. Organic matter losses for these fields ranged from 103 to 392 kg ha^{-1} (Table 3.5).

The effect of canopy cover in reducing erosion losses was evidenced by minimal soil losses obtained, in most plots, after the fifth week of growth despite the occurrence of erosive rainfall. Low canopy development was related to enhanced soil erosion (Figure 3.3). The two fields having the highest incidence of web blight and exhibiting the least canopy development had substantial erosion losses with all erosive rainfalls throughout the growing season.

Effects of Land Use Practices

Effects of fallowing. Based on t-tests, fields that were fallowed has lower incidence of erosion and web blight compared to fields that had been cultivated for two or more years.(Table 3.10 and 3.11). Erosion was probably decreased due to the higher aggregate stability resulting from land fallowing (Hudson, 1976). Web blight, a rain-splash-transferred fungal disease, was probably low in these fields due to a combination of higher aggregate stability and low inoculum levels.

Higher phosphorus availability and microbial biomass levels were closely associated with land fallowing. Increased phosphorus availability due to fallowing is consistent with studies by Ramakrishnan and Toky (1981) and Arnason et al. (1982). These authors, noted, however, that fallows of less than five to ten years may not be sufficient to restore phosphorus fertility in degraded soils. The field in the current study with the highest phosphorus levels had been removed from virgin forest during the previous growing season (Farm 8).

Although the average yields from fallowed fields were almost double the yields obtained from continuously cultivated fields, differences were significant only at the $P=0.284$ level of confidence. The inability of increased soil fertility due to fallowing to significantly increase yields may have been due to the confounding of land-fallowing with crop management practices. The availability of nutrients from fertilizers was confounded with the availability of nutrients from soil reserves. All farmers but one applied a complete fertilizer at the time of planting. Fallowed fields had higher soil

phosphorus reserves at planting than did cultivated fields, but lower rates of fertilizers were applied to these fields.

The regression relationships between yields and available soil phosphorus or phosphorus uptake were very low. This may have been due to the inability of the extraction method used to assess the presence of labile organic forms of phosphorus. The low regression relationships obtained, however, were more likely due to the masking of environmental properties by management aspects. Eilitta et al. (1991) reported low correlations between soil fertility parameters and yields for similar field studies conducted in Nigeria.

Effects of labranza cero. The adoption of labranza cero practices, as recommended by extension agents, did not decrease erosion or result in higher yields (Tables 3.10 and 3.11). The presence of residues on the soil surface did result in a significant decrease in the availability of phosphorus, probably due to immobilization processes. Three farms included in the study (Farms 1, 2, and 3) were farms included in a MAG soil conservation program promoting labranza cero. These fields had a mulch cover composed of maize stubble and weeds from the veranero growing season weighing less than 0.8 tons ha^{-1}. Neither weed nor web blight infestations were controlled at the mulch levels found in these fields. Soil losses due to erosion averaged 3.7 tons ha^{-1}. Farm 2 had near total crop loss due to web blight.

This study also included the field of one farmer innovator who developed his planting practices from independent experimentation. The mulch cover of this field weighed 10.5 tons ha^{-1} and was composed predominantly of jaragua (Hypahenia rufa).

Soil losses due to erosion, web blight infestation, and weed growth were all negligible in this field.

These results show that the mulch produced during a continuous cropping rotation of beans and maize is not sufficient to control erosion, the incidence of web blight, or weed regrowth. Beans are harvested by removing the entire plant, including roots, from the soil. To prevent infestation of growing beans from diseased residues, bean residues are not placed back on the land after threshing. Residues remaining after the maize cropping season are left on the soil. At typical maize production levels of 2 tons ha^{-1}, residues of 2 tons ha^{-1} would be expected. Weed growth during the growing seasons and during the fallow dry season adds additional biomass to the mulch cover. Mulch levels were decreased in the labranza cero fields studied due decomposition and due to the use of the harvested maize fields as pastures for cattle or horses during the dry season.

Effects of burning. Burning resulted in increased soil phosphorus and decreased web blight incidence (Tables 3.10 and 3.11). In tropical soils, phosphorus is stored in the above ground biomass and released during burning (Ewel et al., 1981). All burned-field treatments were subjected to incomplete burns as indicated by the presence of partially burned residues. Web blight incidence was probably reduced due to the destruction of infected bean residues.

Conclusions

Agronomic monitoring of fields provided important information regarding the variability between frijol espeque practices. It also served to identify problems in the

farming system and potential recommendations. The major limitation to bean production was the incidence of web blight. Soil erosion and harvesting resulted in a depletion of nutrients and organic matter from the agroecosystem. In many of the fields studied, long-term soil losses resulted in a removal of the upper soil horizon, the exposure of a rocky subsoil, and the formation of gullies.

Although erosion was associated with lower yields, farmers obtained near-normal yields through the use of inputs. However, the profitability of farming degraded land was low. Returns on investment for farmers farming fallowed land were more than twice the returns on investment obtained from planting continuously cultivated land. Soil conservation methods recommended by extension agents proved ineffective in controlling erosion, decreasing the incidence of web blight, or increasing yields. The ineffectiveness of mulching practices was due to the limited biomass returned to the field in the current rotation practices. For labranza cero methods to be effective, plant biomass returns to the field need to be increased. This may be accomplished through the natural establishment of a grass fallow or through the planting of an accelerated fallow. The need to use harvested land as a dry-season pasture also deters soil conservation measures.

Of the land-use practices studied, land fallowing was the most effective in decreasing soil degradation and increasing the profitability of bean production. Intense land-use pressure, especially near the commercial center, limits the adoption of land-fallowing as a recommendation. Although lack of replication prevents the assessment of statistical comparisons, the jaragua-based labranza cero treatment may decrease the rate of soil degradation while increasing the intensity of crop production.

To more clearly assess the effects of fallow length, labranza cero, and bare-field land preparation practices on crop yields and soil degradation, two on-farm experiments were conducted during the succeeding veranero and inverniz growing seasons. These experiments were designed to study the interaction between land-use intensification and land-preparation practices, and their effects on yields, soil degradation, and profitability.

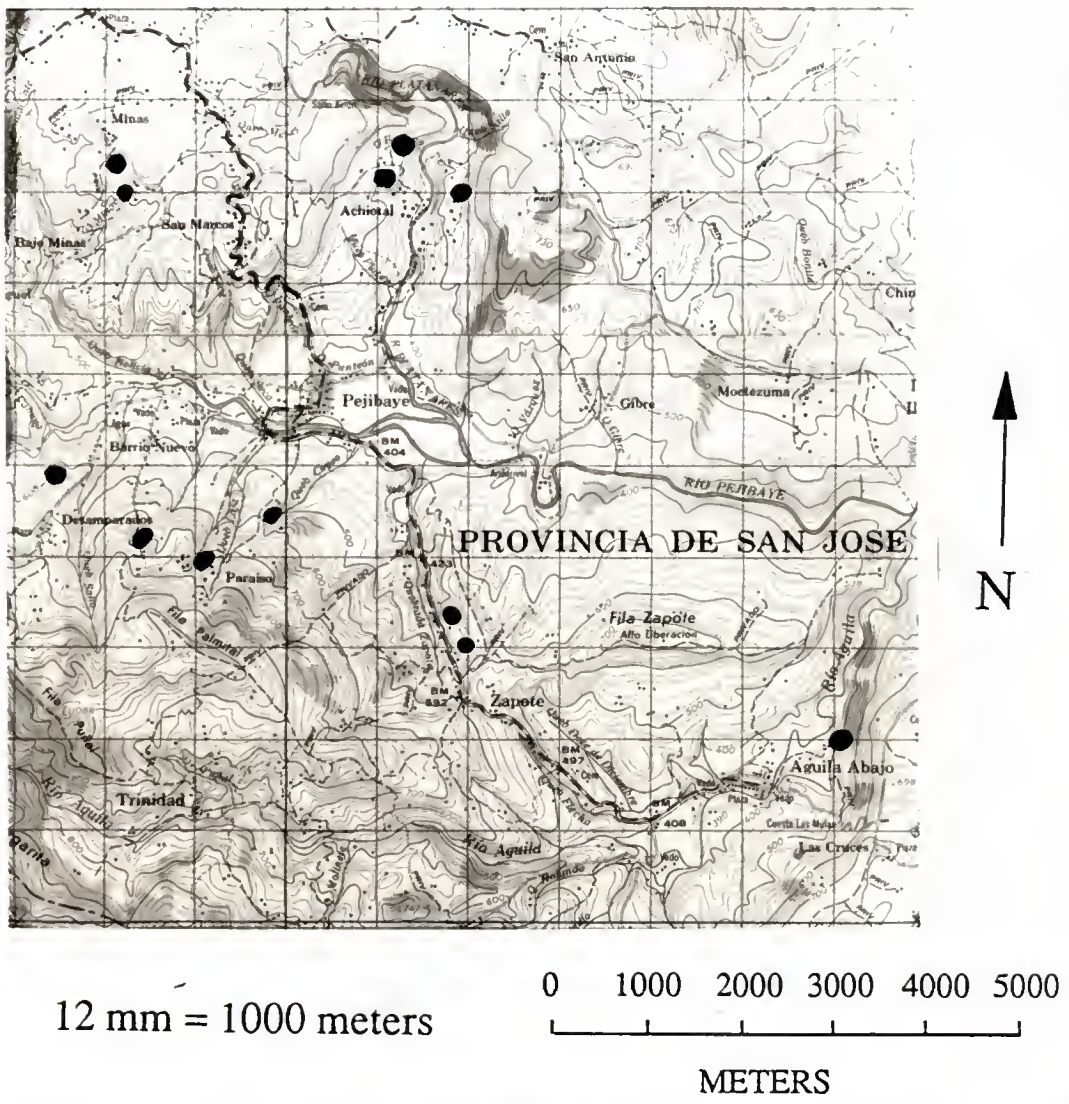


Figure 3.1: Location of farms included in the study in relationship to Pejibaye. (Source of Map: Instituto Geográfico Nacional, 1975)

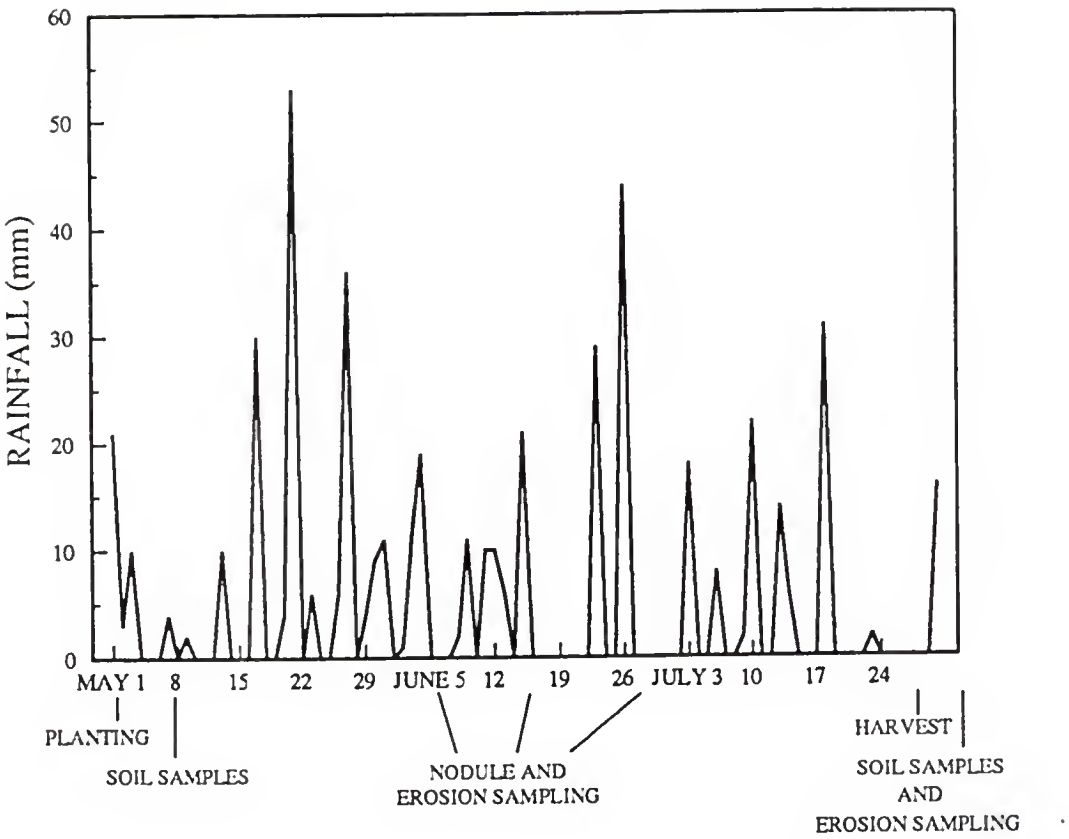


Figure 3.2: Rainfall, agricultural acitivities, and sampling times.

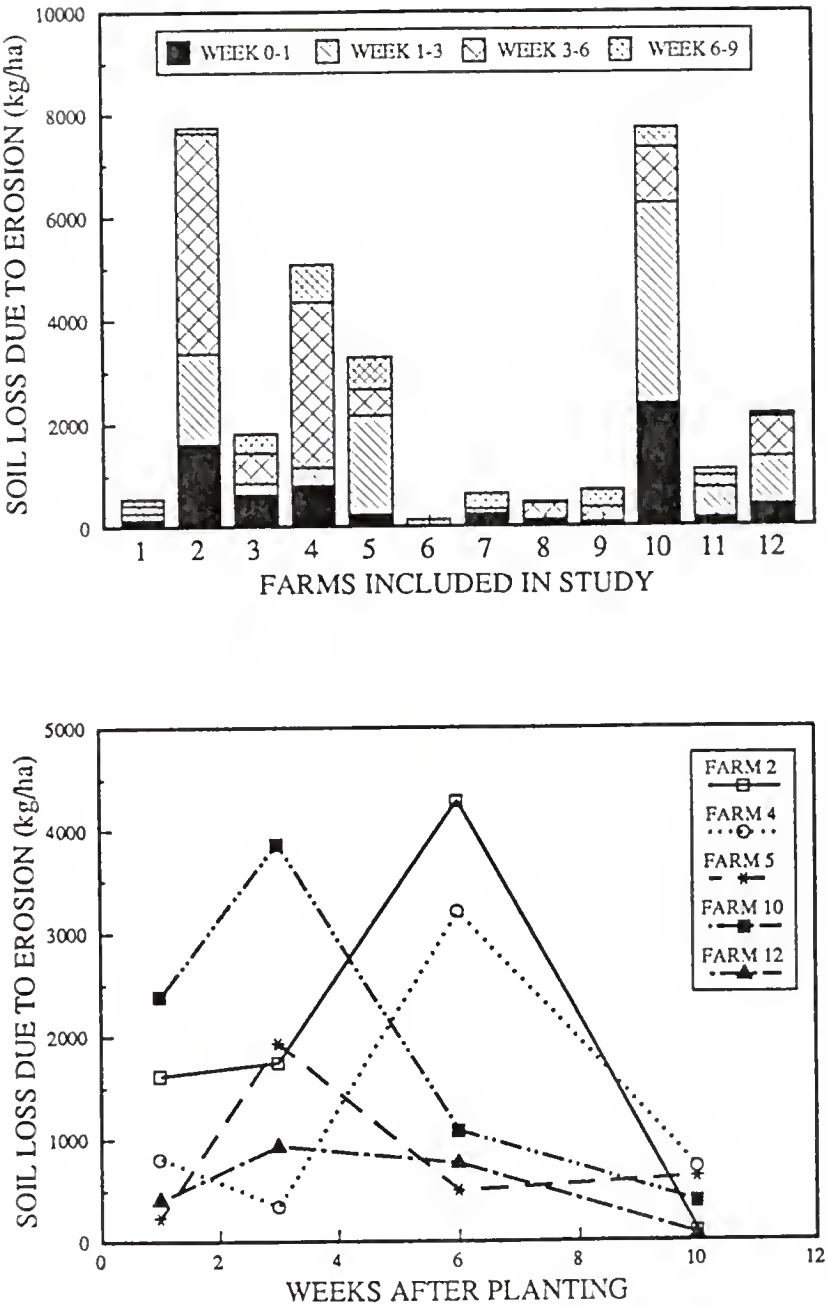


Figure 3.3: Soil losses due to erosion as affected by farm and sampling period.

Table 3.1: Physical description, prior land use, and land preparation methods used on farms included in the study.

FARM	ASPECT	SLOPE (%)	PRIOR LAND USE	WEIGHT OF RESIDUES (kg ha^{-1})	TYPE OF RESIDUES ON SOIL
1	WNW	74	3 years BMR[a]	285	maize residues
2	SW	61	4 years BMR	805	maize residues
3	NW	68	3 years BMR	350	maize residues
4	NNW	57	2 years BMR	300	manually removed
5	SW	68	4 years BMR	185	manually removed
6	SW	55	2 years fallow/ 1 year BMR	10520	grass mulch
7	SW	68	3 years fallow/ tapado	305	burned
8	SW	70	virgin forest/ tapado	970	burned
9	S	71	2 years fallow/ tapado	185	burned
10	SW	63	3 years BMR	340	burned
11	WNW	79	4 years BMR	515	burned
12	SSE	79	6 years BMR	540	burned

a. Continuous bean-maize rotation (2 crops/year).

Table 3.2: Input use on farms included in the study.

FARM	DOP[a]	SEED VARIETY	PLANTING DISTANCE (cm)	HERBICIDE USE (liters ha^{-1} Paraquat)	FERTILIZER USE	OTHER INPUTS[b]
1	5-11	Talamanca	35 x 53	5	130 kg ha^{-1} 12-24-12	F, M
2	5-10	Talamanca	48 x 58	2.5	100 kg ha^{-1} 10-30-10	none
3	5-9	Talamanca	37 x 46	6.5	150 kg ha^{-1} 12-24-12	F, I
4	5-14	Talamanca	38 x 56	8	none	none
5	5-9	Talamanca	39 x 57	5	125 kg ha^{-1} 10-30-10	none
6	5-9	Brunca	50 x 73	4	150 kg ha^{-1} 12-24-12	F, M
7	4-24	Talamanca	35 x 48	6	150 kg ha^{-1} 10-30-10	none
8	5-16	Talamanca	40 x 52	2	65 kg ha^{-1} 12-24-12	F, I
9	5-5	Viña Morada[c]	35 x 44	2	50 kg ha^{-1} 12-24-12	none
10	5-10	Talamanca	45 x 55	7	75 kg ha^{-1} 12-24-12	F, M
11	5-1	Guasteco[d]	53 x 62	4	100 kg ha^{-1} 10-30-10	none
12	5-10	Brunca	48 x 60	2.5	90 kg ha^{-1} 12-24-12	I

a. Date of planting.
b. Fungicides (F), insecticides (I), and molluscacides (M).
c. Traditional variety.
d. Introduced variety.

Table 3.3: Soil characteristics of farms included in the study.

FARM	CLAY (%)	SAND (%)	SILT (%)	pH	OM (%)	P[a] (ppm)	K[a] (ppm)	Ca[a] (ppm)
1	28.9	19.1	52.0	6.4	3.7	5.1	214	2601
2	38.0	9.4	52.6	5.4	4.3	3.5	134	2423
3	24.8	27.4	47.8	7.4	5.5	10.8	286	5204
4	26.0	19.4	54.6	6.2	3.7	5.7	196	2580
5	42.0	6.8	51.2	5.7	3.8	8.1	287	3039
6	27.2	36.4	36.4	6.2	5.5	11.4	239	4125
7	33.2	19.4	47.4	6.3	4.8	5.2	207	3194
8	14.4	36.7	48.9	7.1	5.7	85.1	424	4846
9	36.4	13.8	49.8	6.2	4.9	4.1	194	2931
10	11.2	42.0	46.8	6.3	3.5	23.9	301	3892
11	22.4	23.7	53.9	6.5	4.7	25.3	269	3427
12	12.0	51.0	37.0	6.8	4.2	69.1	170	4226

a. Soil nutrients were extracted using a 4:1 v/w ratio of Mehlich I extract.

Table 3.4: Yield, erosion, nodulation, and pest infestation data for farms included in the study

FARM	YIELD (kg ha^{-1})	EROSION (kg ha^{-1})[a]	NODULE RATING[b]	WEED INCIDENCE[c]	WEB BLIGHT[c]
1	598	556	6.2	3	2
2	157	8122	3.0	1	5
3	1092	2429	4.2	2	0
4	636	5193	3.0	1	4
5	404	3701	4.0	2	3
6	1258	140	5.1	1	0
7	1372	641	4.1	1	1
8	1124	586	5.7	3	0
9	817	915	4.7	2	0
10	768	7990	5.6	2	1
11	913	1106	4.1	4	2
12	753	2298	4.4	3	2

a. Cumulative erosion during the 11 week growing season.
b. Nodules were rated according to nodule number, location, size, and color according to CIAT (1988). Rating is on a scale of 1 (low numbers of and/or ineffective nodules) to 7 (high numbers of effective nodules).
c. Rated on scale of 0 (none) to 5 (complete incidence).

Table 3.5: Soil phosphorus, microbial biomass, organic matter losses due to erosion, and plant nutrient uptake at harvest.

FARM	SOIL P (ppm)[a]	MICROBIAL BIOMASS N (ppm)[b]	OM LOSS DUE TO EROSION (kg ha^{-1})[c]	N IN LEAF TISSUE (%)	P IN LEAF TISSUE (%)
1	7.8	14.4	27.1	2.83	0.24
2	5.7	0.1	288.2	na	na
3	13.2	13.9	101.9	2.54	0.27
4	4.5	7.4	286.6	2.34	0.20
5	8.9	5.5	114.6	2.29	0.26
6	9.1	1.5	6.2	2.97	0.32
7	4.8	30.9	54.6	3.01	0.31
8	60.1	23.0	35.5	2.82	0.38
9	3.6	16.2	48.8	2.32	0.28
10	27.4	12.6	392.5	2.01	0.40
11	26.6	20.3	57.8	2.96	0.36
12	31.4	9.1	113.2	2.79	0.39

a. Soil phosphorus was extracted using a 4:1 v/w ratio of Mehlich I extract.
b. Data presented for microbial biomass are unconverted values.
c. Cumulative erosion losses during the 11 week growing season.

Table 3.6: Economic data for farms included in the study.

FARM	COST OF COMMERCIAL INPUTS[a]	JORNALES[b] LABOR INPUTS	NET RETURN ON INVESTMENT	NET RETURN PER JORNAL OF LABOR[a]
1	8693	23	2.44	908
2	9243	50	0.10	14
3	9901	38	4.88	1016
4	3400	37	8.29	745
5	6250	46	4.32	480
6	7380	27	8.04	1990
7	3475	46	17.81	1320
8	7482	37	6.50	1295
9	2810	28	13.66	1342
10	7132	38	4.64	763
11	5407	43	7.09	784
12	5693	38	4.55	667

a. Values are in Colones ($1 US = 107 Colones, 1-1-91).
b. A jornal is a 6 hour labor day.

Table 3.7: Regressions of soil, plant, and management factors on yields.

VARIABLE	R-SQUARE	PROB > F
Soil organic matter at planting[a]	0.3142	0.0580
Total soil cations at planting	0.3363	0.0030
Soil phosphorus at planting	0.0584	0.2551
Soil phosphorus at harvest	0.0732	0.2011
Microbial biomass at harvest	0.3468	0.0025
Nitrogen uptake[b]	0.2532	0.1146
Phosphorus uptake[b]	0.0183	0.6917
Nodule rating	0.0961	0.1404
Weight of soil surface residues	0.0846	0.1679
Erosion[c]	0.3590	0.0020
Web blight incidence[c]	0.4756	0.0002
Weed incidence[c]	0.0029	0.8012
Commercial input expenses	0.0306	0.4136
Labor inputs	0.0509	0.2890

a. All regression represent direct relationships unless otherwise indicated.
b. Percent of nutrients in leaf tissue at harvest.
c. Negative relationship.

Table 3.8: Regressions of environmental and management factors on net returns

VARIABLE	R-SQUARE	PROB > F
Labor inputs	0.0043	0.8403
Web blight incidence	0.2064	0.1379
Weed incidence	0.0646	0.4252

Table 3.9: Multiple regressions of soil, enviromental, and crop management factors on yields

VARIABLES	R-SQUARE	PROB > F
Soil organic matter[a] Microbial biomass[a]	0.5144	0.0862 0.1142
Weed incidence[b] Web blight incidence[b]	0.6005	0.1005 0.0068
Total soil cations[a] Microbial biomass[a] Erosion[b]	0.6432	0.0075 0.0287 0.0481
Weed incidence[b] Web blight incidence[b] Insect incidence[b]	0.6547	0.1605 0.0111 0.2948
Weed incidence[b] Web blight incidence[b] Erosion[b]	0.6983	0.0444 0.0755 0.1459
Web blight incidence[b] Microbial biomass[a] Weed incidence[b]	0.7884	0.0226 0.0285 0.0159
Nitrogen uptake[a] Microbial biomass[a] Weed incidence[b]	0.8476	0.0153 0.0235 0.0020

a. Direct relationship.
b. Inverse relationship.

Table 3.10: Comparisons of land-use practices: t-test analyses.

	-----PROB > F IN T-TESTS ---		
VARIABLE	LABRANZA CERO	BURNED FIELDS	FALLOWED LAND
Yields	0.532	0.962	0.284
N uptake	0.566	0.597	0.974
P uptake	0.522	0.884	0.323
Soil Ca at planting	0.200	0.353	0.958
Soil P at planting	0.006	0.000	0.160
Soil OM at planting	0.612	0.717	0.540
Soil P at harvest	0.024	0.002	0.065
Microbial biomass at harvest	0.923	0.586	0.119
Nodule ranking	0.318	0.257	0.431
Weight of soil surface residues	0.502	0.879	0.096
Erosion	0.435	0.925	0.004
Weed incidence	0.986	0.596	0.986
Web blight incidence	0.234	0.090	0.083
Net returns on investment	0.592	0.263	0.106
Net returns per jornal	0.053	0.135	0.754
Labor inputs	0.107	0.269	0.735

a. Labranza cero includes farms 1, 2, 3, and 6. Burned fields includes farms 7, 8, 9, 10, 11, and 12. Fallow farms include farms 6, 7, 8, and 9.

Table 3.11: Effect of land-use practices: mean values for variables with significant relationships in t-tests.

VARIABLE	LABRANZA CERO[a]	BARE SOIL
Available P at planting (ppm)	5.2	28.3
Available P at harvest (ppm)	8.5	18.6
Net returns per jornal[b]	982	922

VARIABLE	BURNED[a]	NOT BURNED
Available P at planting (ppm)	35.4	5.8
Available P at harvest (ppm)	23.2	7.4
Web blight incidence[c]	1.0	2.3

VARIABLE	FALLOWED[a]	CULTIVATED
Available P at planting (ppm)	23.9	18.9
Available P at harvest (ppm)	18.7	13.6
Microbial biomass (ppm NH_4)	17.9	10.4
Weight of soil surface residues (tons ha^{-1})	56.5	32.1
Web blight incidence[c]	0.2	2.45
Erosion (tons ha^{-1})	0.57	3.92
Net returns on investment[b]	11.5	4.5

a. Labranza cero includes farms 1,2,3, and 6. Burned fields includes farms 7,8, a9, 10, 11, and 12. Fallowed fields includes farms 6,7,8, and 9.
b. In Colones. ($1 US = 107 Colones, 1-1-91).
c. Rated on a relative scale of 0 (no incidence) to 5 (complete incidence).

CHAPTER 4
THE EFFECT OF LAND-USE INTENSITY AND PLANTING METHODS ON BEAN YIELDS AND SOIL DEGRADATION

Use of Modified Stability Analysis to Compare Frijol Tapado and Frijol Espeque

Difficulties of Comparing Frijol Tapado and Frijol Espeque

Changes in bean planting methods and intensity of land use have affected both bean yields and the sustainability of soil resources. In the traditional practice of frijol tapado, one crop of beans is obtained following three to four years of fallow. Population pressure and land-use competition have caused a progressive decrease in the ratio of fallow to cropping. Most frijol tapado now is produced on land fallowed for only one or two years. The shorter fallows result in decreased regeneration of soil fertility and decreased diversity in the fallow growth.

Frijol espeque, an agrochemical input-based, straight-row, dibble-stick planted bean production method was introduced to allow farmers to adopt continuous cropping practices. Through the use of agrochemical and crop maintenance labor inputs, significantly higher yields have been reported for frijol espeque compared to frijol tapado (Pachico and Borbón, 1986). Adoption of this method by farmers cultivating steep slopes may be causing both soil degradation and decreasing profitability of bean production. Typically, frijol espeque is planted on cleared fields. Planting on cleared fields

encourages high rates of soil erosion, since fields typically used for bean production have slopes of 50% or more. Cleared fields also provide conditions favorable for the dissemination of web blight inoculum.

Few agronomic studies comparing frijol tapado and frijol espeque have been conducted. Comparisons between the two practices are problematic. Due to labor availability, rainfall, and pest infestations, frijol espeque is usually planted during the inverniz growing season (May-July) and frijol tapado during the veranero growing season (October-December). Thus, studies comparing the two planting systems during the same growing season may not provide reliable information for the production method not usually planted during that season.

Land-use practices for frijol espeque and frijol tapado also differ. Frijol tapado is always planted on land that has been fallowed for at least one year. Frijol espeque is usually planted following the harvest of frijol tapado, or as part of a continuous bean-maize rotation. It is rarely planted as the first crop after clearing a fallow. Accordingly, comparative studies conducted on fallowed fields will be biased in favor of frijol espeque while comparative studies conducted on continuously cultivated land will be biased against frijol tapado.

Previous agronomic studies of frijol tapado were designed to describe the system (Monge et al., 1987; Araya and González, 1987) or assess the response of the system to input use. On-farm trials conducted by von Platen and Rodríguez (1982) showed that yields of frijol tapado were significantly increased by the application of fertilizers and pesticides. The only two studies that directly compared frijol tapado and frijol espeque

were conducted on experiment stations. Shenk et al. (1979) demonstrated that by substituting dibble-stick planting for broadcast planting, yields were substantially increased. Rosemeyer (1990) obtained significant yield responses by both frijol espeque and frijol tapado when complete fertilizers were applied. When no fertilizers were applied, frijol tapado produced significantly higher yields than did frijol espeque planted on manually cleared fields.

Although many studies refer to the higher potential for erosion in frijol espeque production than for frijol tapado (von Platen and Rodríguez, 1982; Ballestero, 1985; Araya and González, 1987), these differences have never been assessed. Previous studies have focused only on evaluating technologies for increasing yields. The relationships between fallow length, planting method, and soil degradation also have not yet been determined. The present studies were conducted to assess the effect of land-use intensity and planting method on bean yields and soil degradation. To evaluate differences in the interactions between land-use intensity and planting method, the study was conducted in nine environments using Modified Stability Analysis.

The Modified Stability Analysis Method and On-farm Trials

Modified stability analysis (MSA) is based on a statistical method developed to facilitate the assessment of genotype by environmental interactions. In plant breeding studies, researchers are interested in identifying varieties that are yield-responsive to changes in the environment or to the applications of inputs. Yates and Cochran (1938) showed that differences between responsive varieties and non-responsive varieties could be accounted for based on linear regression analyses. They substituted an index based

on physical or biological environmental factors with an index based on the mean yield of all varieties at each location. The yield of each variety at each location is regressed against this mean yield index. These calculations can provide genotype by environment (GxE) relationships between varieties and native soil fertility, or responses of varieties to fertilizers or management practices.

Agricultural technology recommendations involve changes in land use, plant varieties, and input use. Just as plant varieties exhibit a GxE interaction, agricultural technology recommendations respond differently to different environments. For example, farmers with access to credit, inputs, and fertile land are able to realize the yield potential of green revolution technologies. Resource-poor farmers working more marginal lands require low risk technologies. Appropriate recommendations for the latter group of farmers are not technologies that produce maximum yields in the best years but, instead, technologies that produce stable yields even in the worst years.

Farmer groups can be separated into *recommendation domains* based on differences in socioeconomic or environmental conditions. Farmers in different recommendation domains have different abilities to adopt agricultural recommendations. Locations within a farm may also be treated as separate recommendation domains based on differences in environmental conditions, such as soil fertility or land-use intensity (Stroup et al., 1991).

Agricultural experiments designed to be analyzed using ANOVA statistics are not designed to assess GxE interactions. Consequently, they provide an insensitive mechanism for identifying treatments suitable for different recommendation domains. To increase the potential for obtaining statistically significant differences among

treatments, experiments analyzed with ANOVA are usually designed to minimize treatment by environment interactions (Hildebrand, 1990). In contrast, the evaluation of treatment response to recommendation domains requires an experimental design that exploits treatment by environment interactions.

Modified stability analyses recommended by proponents of FSR/E (Hildebrand and Poey, 1985) differ from GxE analyses used by plant breeders in terms of data interpretation (Russell, 1991). Plant breeding research has traditionally been designed to separate varieties that are responsive from varieties that are stable to environmental conditions. Using MSA, responsive varieties are indicated by regression coefficients greater than one while more stable varieties are indicated by regression coefficients less than one. In contrast to plant breeding research, farming systems research is particularly interested in identifying agricultural technologies that produce stable yields even in poor environments. These treatments represent low-risk technologies that are suitable for resource-poor farmers. Using MSA, technologies with these characteristics would have regression coefficients near zero.

Modified stability analyses have been used effectively in evaluating experiments involving on-farm trials (Hildebrand, 1984; Singh, 1990; Russell, 1991). Since MSA is based on regression analyses, experimental designs can be limited to a single block of treatments per farm. To assess treatment differences under these conditions, Stroup et al. (1991) recommended the use of an ANOVA procedure that partitions out, from the residuals, two terms related to the regression analysis. The two terms are the treatment by linear component of environmental index and the treatment by quadratic component of environmental index. The environmental index corresponds to the mean yield for

treatments across environments. In the ANOVA, each of these terms have t-1 degrees of freedom. Obtaining a significant F value for these terms indicates that the treatments can be separated by recommendation domain.

Since environmental indices are based on mean yields, and not on actual environmental data, they are only a relative indicator of differences between environments. Values obtained for environmental indices are dependent on the set of environments used and on the specific treatments included in the experiments (Russell, 1991). A set of environments which differ due to rainfall will produce a different response curve than a set of environments which differ due to soil fertility. Due to these limitations, MSA is considered most appropriate as a preliminary means of investigation (Stroup et al., 1991). The validity of environmental indices, as representing the cause for environmental response, can be evaluated by comparing yields against assessed environmental parameters (Westcott, 1985). Since measurement of environmental data is costly, MSA provides a means of analyzing treatment response to environment when project funds are limited.

Assessment of sustainability involves not only the effect of treatments on yield, but also the effect of treatment on degradation factors. Analyses of farmers' practices of frijol espeque showed that inputs can mask the effects of soil degradation. Modified stability analyses can be used to assess the effects of environmental and input variables on degradation as well on yields.

Materials and Methods

Field Analyses

Farms. Nine farms dedicated to frijol tapado were chosen based on farmer interviews and field inspection. The location of the farms in relation to Pejibaye is shown in Figure 4.1. To the extent possible, farms chosen had similar slopes and soil texture (Tables 4.1 and 4.2). The nine farms were selected to represent a range of land-use intensity (Table 4.1).

Vegetation. Prior to planting, leaf samples were collected from the plants dominating fallows at each farm. Common names of plant species were provided by local farmers (Table 4.1). Identification to scientific name was based on descriptions given by Pittier (1957).

Field preparation, planting and maintenance. Experimental treatments were installed one block per farm. Each block was 30 meters wide by 20 meters long. Blocks were subdivided into five plots, with each plot being five meters wide by 20 meters long. A one meter buffer strip was left between plots. Treatments (Table 4.3) were assigned randomly among the five plots. Experimental plots were planted between October 10 and 18, 1990 using certified bean seeds of the Type II bean variety "Brunca". Preliminary germination tests indicated a germination rate of 99+%. Frijol espeque treatment plots were seeded using a dibble-stick, 2 seeds per hill, 35 cm between hills and 50 cm between rows. The frijol tapado treatment was broadcast-planted. All treatments were planted at a rate of 26 kg ha^{-1}.

To control slug damage, a molluscacide (MataBabosa Bayer) was broadcast onto each treatment at the rate of 8.3 kg ha^{-1}. Herbicide application methods are described

in Table 4.3. Complete fertilizer (10-30-10; N-P_2O_5-K_2O) was applied at a rate of 50 kg ha^{-1} seven days after planting. Fertilizer was applied to frijol tapado and labranza cero treatments by broadcasting. In the other three treatments, fertilizer was applied, using a dibble-stick, approximately 8 cm to the side of the plant. All frijol espeque treatments were hand-weeded three weeks after planting.

Soil analyses. To assess the effect of treatments on soil nutrient availability, soil samples were taken at planting and at harvest. Bulked soil samples were taken, using a shovel, to the 0-15 cm and 15-30 cm depths. These two soil depths were chosen to represent nutrient availability in and below the bean rooting zone, respectively. Eight subsamples, taken along a vertical transect within the treatment plot, were bulked to form each soil sample prior to analysis. Sub-samples from the bulked soil sample were air-dried and ground to pass a 20-mesh sieve. Available P and K were assessed following extraction with Bray II extractant (Olsen and Sommers, 1982). Organic carbon was determined using a Walkley-Black procedure (Nelson and Sommers, 1982). Soil pH was analyzed using a 2:1 soil-water paste.

Nitrogen mineralization in the soil rooting zone was assessed using the buried bag technique (Raison et al., 1987). Twice during the growing season, minimally disturbed soil cores from individual 0-15 cm soil samples were extracted using a shovel and carefully transferred to polyethylene bags so as to maintain soil structure and horizonation. The bagged soil cores were immediately buried to the depth of sampling and covered with a thin layer of soil. Eight bags were prepared and buried per treatment plot. In treatments containing surface residues, residues were not included in the bag but

were placed over the soil layer covering the buried bag. The first set of bags was buried at planting and collected 25 days later. The second set was buried 25 days after planting and collected after 45 days of in-field incubation. Soil sub-samples from the buried bags and from soil samples taken at the time of burial were extracted with 2 N KCl. Extraction was conducted within 24 hours of sample collection. Extracts were analyzed colorimetrically for NO_3-N using a Technicon AutoAnalyzer (Technicon, 1978). Since analyses could not be conducted immediately following extraction, extracts were preserved by adding 1 ml of 1% $HgCl_2$ to each liter of 2 N KCl used for the extractions. All sample extracts were stored at 5° C prior to colorimetric analysis. Mineralized nitrogen was calculated by subtracting the concentration of nitrate nitrogen in soil extracts at the time of sample burial from that in the incubated samples.

Erosion assessments. To determine soil losses due to erosion, run-off sub-plots, 2.5 m wide by 20 m long, were installed in each plot. The run-off plots were installed during the first week of October. Barriers at the upper edge, and collection troughs at the lower edge, of the erosion plots were carefully placed on the contour of the land. Vertical barriers were formed by shallow trenches. The collection trough had a capacity of approximately 200 liters. Soil in the collection troughs was collected during the last week of October and the during the last week of November. Collected soil was air-dried and weighed. Sub-samples from the first collection period were ground and analyzed for available P and K, and for organic carbon, using the procedures described above. Potential erosivity was monitored by measuring the amount and relative intensity of rainfall throughout the experimental period.

Aggregate stability. Aggregate stability, at harvest, was determined on sub-samples of bulked soil samples from the 0-2 cm depth. Samples were also taken from undisturbed fallows adjacent to the treatments. A modification of the wet-sieving techniques described by Yoder (1936) and Kemper and Chapil (1965) was used. Twenty-five grams of air-dried aggregates were placed on the top-most sieve of a nest of sieves having mesh sizes of 2.0, 1.0, 0.5, and 0.25 mm. The sieves were placed in a bucket of water and the soil samples were allowed to soak for one minute. The samples then were sieved manually under water for ten minutes (50 strokes $minute^{-1}$). Soil remaining on each sieve was dried at 105° C and weighed. Separate, unsieved, 10 g samples from each soil were dried at 105° C and weighed to compute moisture corrections.

Nitrogen inputs from residues. To assess nutrient inputs from mulch residues remaining on the soil surface in the frijol tapado and labranza cero treatments, triplicate samples of residues within a 0.25 square meter quadrant were collected one week prior to planting and, again, one week after harvest. Residue samples were dried and weighed. Residue subsamples were ground using a Wiley mill. Ground samples were analyzed for N using the Kjeldahl digestion method (Bremner and Mulvaney, 1982). Phosphorus and potassium were assessed using a Technicon AutoAnalyzer following ashing and dissolution in 10 N HCl. Nutrients mineralized from residues were determined by subtracting nutrients in plant residues at planting from litter nutrients at harvest.

Nutrient uptake by beans. Uptake of nutrients by the crop plant was assessed at physiological maturity, using leaf samples. Leaf samples were collected six weeks after

planting, dried, ground, and analyzed for N, P, and K using the methods described above.

Nodule numbers. Relative nitrogen fixation by beans was evaluated 35 days after planting. Sixteen plants (8 hills in espeque-planted treatments) were collected per plot. The nodules on each root were counted and the average number of nodules per plant determined. Due to sampling problems, data from only six farms are included in the analysis.

Bean yields. Bean yields were determined based on the harvest of all bean plants growing within a 3 m^2 quadrant. For each plot, determinations were made in triplicate and the values thus obtained were averaged. Seeds collected from harvested plants were dried and weighed.

Weed infestation. At harvest, all weeds from the same 3 m^2 quadrants used for yield assessments were weighed to measure weed competition in each treatment.

Statistical Analyses

Treatment effects were analyzed using a modified stability analysis design containing nine environments with five unreplicated treatments per environment. Significant differences between treatments were assessed using the statistical model suggested by Stroup et al. (1991). Analyses were conducted using the GLM program of the SAS statistical program (SAS, 1985). Regression analyses of yields against the environmental index, as represented by the mean yields of all treatments within each environment, were conducted according to Yates and Cochran (1938). This GxE analysis technique was extended to determine the relationship of erosion to environment.

Regression and correlation analyses between yields, environmental effects and factors of degradation were assessed using the regression procedure of the SAS statistical program (SAS, 1985).

Results and Discussion

Environmental Factors

Fallow vegetation. Farms that had been fallowed less than two years were dominated by grasses. Fallows of two to three years consisted of a combination of herbaceous plants, shrubs, and small trees (stem diameter < 7 cm). The oldest fallow (4 years) exhibited a closed canopy forest regrowth, an elimination of understory growth, and a mull horizon on the soil surface. The three fields that were in fallow for the longest period of time were used as occasional horse pastures during the fallow period.

Rainfall. Precipitation for the three month growing season was 815 mm, as measured in the municipality of Pejibaye. Twelve storms had intensities greater than 20 mm within a single hour. Relationships between rainfall, bean production activities, and sampling periods are illustrated in Figure 4.2.

Soil Analyses

Soil nutrients and organic matter. Soil fertility varied significantly between farms. This was expected since farms were chosen to represent different intensities of land use. Analyses for organic matter conducted at planting ranged from 3.68% to 4.88%. Soil phosphorus at planting ranged from 4.10 ppm to 62.34 ppm (Table 4.2).

The availability of plant nutrients, particularly phosphorus, was affected by soil clay content. Clay contents of farms included in the studies ranged from 8.8% to 31.2%.

The choice of experimental design placed a priority on obtaining treatment by environmental interactions rather than obtaining significant differences between treatments based on ANOVA. As a result, no significant differences between treatments were obtained for soil organic matter or phosphorus at either planting or harvest sampling periods for either depth analyzed (Table 4.4 and 4.5). Although statistical differences were significant only at the 0.56 level of confidence, average soil phosphorus values for the frijol tapado treatment at planting were only 61% of those calculated for the labranza cero treatment. The greater decomposition of the fallow residues from the labranza cero treatment compared to the frijol tapado treatment was probably responsible for this apparent difference in phosphorus availability.

Fallow growth of the labranza cero treatment was cut approximately one month prior to when the initial soil samples were taken. Fallow residues of the cleared-field (bare-field, G. sepium, and windrow) frijol espeque treatments were cut simultaneously with the cutting of residues for the labranza cero treatment, but residues were removed from these treatments two weeks after cutting. The mulch layer of the labranza cero treatment remained on the soil surface and was subject to mineralization processes from the time of fallow cutting through the onset of the first incubation experiment. The G. sepium mulch was placed on the soil surface at planting, one day prior to initiation of the mineralization experiments. Frijol tapado fallows were cut only one day prior to soil sampling.

Significant differences between treatments for soil potassium were obtained at planting and at harvest. The labranza cero treatment had the highest level of soil potassium at planting while the lowest soil potassium was recorded in the Gliricidia sepium treatment. Differences were probably due to the dissimilarity in the residence time of mulches on the soil surface between the two treatments. Potassium is a mobile cation which is readily leached from residues.

Nitrogen mineralization and microbial biomass. The labranza cero treatment exhibited the highest level of nitrogen mineralization during the first four weeks of the growing season (Table 4.6). During the second half of the growing season, the G. sepium mulched treatment exhibited the highest nitrogen mineralization. Throughout the growing season, nitrogen mineralization was least for the frijol tapado treatment. Although statistical differences for microbial biomass nitrogen among treatments were only significant at the 0.67 level of confidence, the lowest levels were again obtained for the frijol tapado treatment.

During the first half of the growing season, the rate of nitrogen mineralization from mulching materials was confounded by time of application. Although the G. sepium mulch was more succulent and had a higher nitrogen concentration than the fallow residues, time of application of the two materials differed by almost one month.

The higher nitrogen mineralization values obtained for the labranza cero and frijol espeque treatments compared to the frijol tapado treatment may have also been due to the application of herbicides. No herbicides were applied to the frijol tapado treatment. The herbicides glyphosate and terbacil have been reported to stimulate nitrogen

mineralization (Goring and Laskowski, 1982). The stimulation of nitrogen mineralization by herbicides is due to the use of microorganisms killed by herbicides as a nitrogen-rich substrate for growth and decomposition activities of other soil microorganisms (Haynes, 1986). Conversely, the lower nitrogen mineralization rates recorded in the frijol tapado treatment may have been due to the uptake of nitrogen by the bean roots growing through the soil-mulch interface. Roots from the frijol tapado treatment had a very shallow rooting depth, typically growing on the soil surface or within the residue mulch. Shallow rooting is typical of mulch based systems and was also reported for frijol tapado treatments studied by Rosemeyer (1990).

Nitrogen mineralization during the initial sampling period was closely correlated with soil phosphorus availability for the labranza cero and bare-field frijol espeque treatments ($R=0.615$ and 0.606, respectively). As phosphorus is removed from the system, the N:P ratio increases. As a result, phosphorus may become rate limiting for nitrogen mineralization activities (McGill and Cole, 1981). Arnason et al. (1982), studying the effect of the increasing intensity of shifting cultivation practices on nutrient-uptake by maize, attributed low nitrogen-uptake levels to limited soil phosphorus availability.

Penetrometer resistance and aggregate stability. Penetrometer resistance at harvest was greatest for the bare-field frijol espeque treatment. Mulched treatments offered the least resistance to penetration (Figure 4.3a). Aggregate stability analyses were conducted on fallowed land adjacent to the plots as well as on the treatment plots. Fallowed land, frijol tapado, and labranza cero treatments had a greater percentage of

soil surface aggregates larger than 2.0 mm than did the cleared-field frijol espeque treatment (Figure 4.3b). Treatments that had the highest percentage of aggregates greater than 2.0 mm also had the lowest percentage of aggregates in the 0.5 mm to 1.0 mm range.

The retention of mulches over the soil surface decreased soil physical degradation. Both the frijol tapado and labranza cero treatments exhibited greater aggregate stability and lower penetrometer resistance than did the cleared-field frijol espeque treatments. Although differences were not significant, the aggregate stability of the labranza cero and frijol tapado treatments was less than that of adjacent areas remaining in fallow. Mulch covers protect fields from the effects of soil crusting and aggregate disintegration caused by raindrop impact. To maintain or enhance aggregate stability, however, the presence of plant roots and their associated mycorrhizae is required (Jastrow and Miller, 1990).

Plant Analyses

Mid-season plant analyses The G. sepium mulch treatment exhibited the highest average values for nodulation of bean plants and for nitrogen uptake (Table 4.7). Nodule numbers from the G. sepium treatment were significantly greater than nodule numbers from the frijol tapado treatment. Determinations of nitrogen in leaf tissue ranged from 4.38% for the bare-field frijol espeque to 4.69% for the G. sepium treatment, but differences were only significant at the 0.24 level of confidence. The lack of significant differences for nitrogen uptake among treatments was probably due to a combination of high native soil fertility, due to the use of fields which were in fallow prior to the onset of the experiments, and the addition of a complete fertilizer to all treatments. The farm

with the lowest overall yields (Farm 1) did exhibit substantially lower nitrogen uptake for the bare-field and windrow frijol espeque treatments compared to the other treatments.

The low nodulation exhibited by beans from the frijol tapado treatment was probably due to the minimal contact the bean roots had with the soil and soil-borne rhizobia. Bean nodulation for the G. sepium treatment was not closely correlated with nitrogen uptake. Although nodulation in this treatment was not closely correlated with phosphorus uptake, phosphorus from the decomposition of the G. sepium mulch may have enhanced nodulation. The enhanced availability of phosphorus for plant growth for the G. sepium treatment compared to the bare-field and windrow frijol espeque treatments was indicated by the lower correlation between yields and phosphorus uptake for the latter two treatments compared to the G. sepium treatment (Table 4.8).

The labranza cero treatment exhibited the highest average values for phosphorus uptake. Differences were only significant when this treatment and the windrow frijol espeque treatment were compared (Table 4.7). The higher availability of phosphorus from mulched-field treatments is consistent with studies conducted by Rosemeyer (1990). Her studies showed that frijol tapado treatments exhibited higher phosphorus availability and yield responses to phosphorus inputs compared to bare-field frijol espeque treatments. For the nutrient-poor, high phosphorus-fixing soils of the tropics, phosphorus mineralization from mulches can provide a substantial portion of the labile phosphorus pool. The potential of the soils included in the study to fix phosphorus was indicated by the close and inverse correlation between phosphorus availability at planting

and soil clay content for the bare-field and windrow frijol espeque treatments (R=0.809 and 0.628, respectively). Yields for the windrow and G. sepium frijol espeque treatments also were inversely correlated with soil clay content (Table 4.8). The application of green manure mulches to fields in the Amazon Basin (Wade and Sanchez, 1983) and the decomposition of cut fallows in Malaysia (Andriesse and Schelhaas, 1987b) each resulted in significant increases in phosphorus availability.

Litter inputs. The weight loss from the mulch layer of the labranza cero treatment was double the weight loss obtained for the frijol tapado treatment. The average change in weight of the mulch layer for the labranza cero treatment during the growing season was 10.6 ton ha^{-1}, compared to 5.3 tons ha^{-1} for the frijol tapado treatment. The greater decomposition of residues observed for the labranza cero treatment was probably due to the earlier cutting of the fallow growth for this treatment. The G. sepium mulch layer, weighing 1.23 tons ha^{-1} (dry weight basis), contained 36 kg ha^{-1} of nitrogen and 2.3 kg ha^{-1} of phosphorus.

Disease and pest infestation. Molluscacides which were used adequately controlled slug infestations. Web blight infestations did not occur in any of the treatments.

Weed infestation. The weight of weeds at harvest was greatest for the frijol tapado treatment and least for the labranza cero treatment, but these differences were significant only at the 0.82 level of confidence.

Yields

Yield differences among treatments. The three cleared-field frijol espeque treatments produced significantly higher yields than the labranza cero treatment. Yields from the frijol tapado treatment were significantly lower than yields obtained from any of the frijol espeque treatments (Figure 4.4a). Frijol tapado yields were only 53% of the yields obtained from the bare-field frijol espeque treatment. Although bean stand counts were not calculated, visual field observations indicated that low emergence rates were probably responsible for the lower yield obtained from the frijol tapado treatment.

To obtain yield data that were not confounded by planting rate, all treatments were planted at a rate of 26 kg of seed ha^{-1}. In practice, frijol tapado is usually planted at rates of 25 to 40 kg ha^{-1}, with higher seeding rates being used when the germination rate of the seeds used is known to be low or for fields with short-duration fallows. Differences in yield per hectare for frijol tapado and frijol espeque may have been reduced had a higher seeding rate been used for frijol tapado. Consequently, this experiment only provided a valid comparison among the four dibble-stick-planted treatments with regard to yields per hectare. Comparisons between the frijol espeque and frijol tapado treatments are valid based on kilograms of beans harvested per kilogram of beans planted.

For farmers, who use beans both as a source of seed and for their subsistence, this latter criterion may be more important than yield per hectare. Despite land-use intensification, farmers usually refer to the extensiveness of their planting in terms of kilograms of seed planted and to their agricultural productivity in terms of yield per kilogram of seed planted.

Separation of treatments into recommendation domains. Highly significant differences in yields were obtained between farms (Table 4.9). Due to high within-treatment variability, however, treatments only could be separated into recommendation domains based on the analysis of treatment by linear component of the environmental index at the 0.40 level of probability (Figure 4.4b and Table 4.9).

In comparing the stability or adaptability of different varieties of barley, Finely and Wilkinson (1963) plotted regression coefficients obtained from stability analyses against treatment mean yields. They defined varieties having coefficients of regression approximating one and high mean yields were well adapted to all environments. Conversely, varieties adapted to unfavorable environments had low mean yields and regression coefficients less than one. Varieties that were highly responsive to environmental conditions had regression coefficients greater than one. Based on this classification method, and the criterion of yields based on kg ha^{-1}, frijol tapado would be classified as poorly adapted to all environments, labranza cero as specifically adapted to unfavorable environments, bare-field frijol espeque as specifically adapted to unfavorable environments, while the G. sepium and windrows frijol espeque treatments would be classified as being well adapted to all environments (Figure 4.5 and Table 4.10).

This study was biased in favor of the clear-field frijol espeque treatments since the environments included in this experiment were less degraded than the environments usually used by farmers to produce frijol espeque. Frijol espeque is typically produced using land that has been in continuous cultivation. Due to increased build-up of inoculum and seeds, web blight and weed infestations would be more prevalent under

continuous cropping than when the land is placed in a regular fallow. Mulching has been shown to be effective in controlling web blight (Galindo et al., 1983) and weed growth (Wade and Sanchez, 1983). In the current experiments, negligible levels of web blight were observed for all treatments and environments. This was due to a lack of inoculum in the fields, combined with low rainfall during the period of growth when beans were most susceptible to the disease.

The bias in favor of the cleared-field frijol espeque treatments may have been responsible for preventing a clear separation of treatments into recommendation domains. Had "poorer" environments of continuous cropping been included in the study, yield differences between labranza cero and bare-field frijol espeque treatments may not have been significant.

The environmental bias of this experiment would have favored the recommendation of the cleared-field frijol espeque treatments if statistical analyses had been limited to ANOVA (Figure 4.4a). By analyzing treatments using MSA procedures, additional information regarding treatment response was obtained. This additional information included: the specific adaptation of bare-field frijol espeque treatment to favorable conditions, the potential for the G. sepium and windrow frijol espeque treatments to maintain high yields as the environment becomes degraded, and the specific adaptability of the labranza cero treatment to unfavorable conditions.

Environmental factors affecting yields. No significant relationships were obtained for regressions of mean values, in each location, of soil nutrients, erosion, or weed incidence against the environmental index for yields. The regression of fallow-length

duration against the environmental index produced an R^2 value of 0.62 (Figure 4.6a). Multiple regression analyses showed that yields were affected by a combination of environmental factors. A combination of phosphorus uptake, available soil phosphorus, and nitrogen mineralized during the first sampling period accounted for 59% of the variability in yields. The impact of environmental factors on yields varied by treatment. Based on modified stability analyses, the cleared-field frijol espeque treatments were identified as being more responsive to improvements in environmental conditions than were the two mulched-field treatments. By analyzing the cleared-field frijol espeque treatments separately, a significant regression relationship between phosphorus uptake and the environmental index for yields was obtained (Figure 4.6b).

Correlation analyses, by treatment, indicated that yields of the bare-field frijol espeque treatment were significantly correlated with weed incidence and fallow length (Table 4.8). Labranza cero yields were significantly correlated with weed incidence and fallow length. Frijol tapado yields were only significantly correlated with fallow length.

The cleared-field and mulched-field treatments responded differently to environmental conditions. For the bare-field and windrow frijol espeque treatments, yields were closely related to phosphorus uptake. The removal of fallow residues from these treatments prior to planting limited phosphorus inputs from mulch decomposition. Increased phosphorus uptake in the bare-field treatment was significantly correlated with increased time in fallow ($R=0.769$). For the mulched-field treatments, the decomposing mulch layer provided phosphorus to the system, but inhibited bean emergence. Short-

term fallows consisting primarily of thick pasture grasses inhibited bean emergence more than the more permeable mulches formed from tree trunks and branches of older fallows.

Soil Erosion

Erosivity and soil erodibility. The quantity of rainfall during the present veranero growing season was over 1.60 times the rainfall received during the previous inverniz growing season. Similarly, twice as many erosive storms were recorded during the veranero than during the inverniz growing season. Despite the higher rainfall erosivity, the highest erosion losses obtained during the 12 weeks of the current experiments (103 kg ha^{-1}) were only 1.5% of the highest erosion losses recorded during the same time period during the initial studies. Some of these difference may have been due to the set-up of the erosion plots and/or overflow of the collection trough (See Appendix D). The low erosion losses obtained during the veranero growing season were probably due more to the low erodibility of the soils of the environments studied.

Erosion was inversely correlated with the duration of fallowing for the G. sepium treatment (Table 4.11). Across treatments, increasing erosion losses were closely related to decreasing soil calcium in the topsoil at planting (Figures 4.7a and 4.7b). Most of the across-treatment response was due to the highly significant relationship between soil calcium and soil losses due to erosion for the bare-field and windrow frijol espeque treatments (Table 4.11)

The higher erodibility of soils with low soil calcium and total soil cation levels is related to the poor aggregate stability of these soils. Aggregate structure is maintained by chemical bonds between organic matter and calcium (Farres, 1987). Although

cleared-field treatments exhibited both high erosion loss and low aggregate stability, no significant correlations were obtained among aggregate stability, soil calcium, and soil erosion.

Soil loss due to erosion. Soil erosion was significantly greater for the three cleared-field frijol espeque treatments than for either the labranza cero or frijol tapado treatments (Figure 4.8a). Soil losses due to erosion for the bare-field frijol espeque treatment averaged 6.5 times more than for the frijol tapado treatment. Erosion losses from labranza cero and frijol tapado treatments were minimal and unaffected by differences in the weight of litter on the soil surface. For the labranza cero and frijol tapado treatments, initial litter weights ranged from 7.0 to 30.7 tons ha^{-1}. The mulching rate used for the G. sepium treatment was insufficient to significantly decrease soil erosion compared to the other cleared-field frijol espeque treatments.

No significant differences in erosion losses were observed between bare-field and windrow frijol espeque treatments when data from all of the environments were averaged together in ANOVA. Farm-by-farm comparisons of the two treatments showed that windrows composed of tightly compacted grassy material (Farms 1, 2, 5, 7) reduced erosion by approximately 50% compared to the bare-field treatment. For farms with windrows composed of porous, woody materials, the presence of the windrow did not decrease soil loss collections. For the labranza cero treatment, increased fallow duration was directly correlated with soil losses due to erosion (Table 4.11). This further indicates that grassy mulches were more effective in controlling soil erosion than woody mulches.

Erosion losses were not sufficient to affect yields. A highly significant direct correlation between increased yields and erosion was obtained for the labranza cero treatment. For this mulched-field treatment, increased erosion losses were associated with woody fallows. Woody fallows impeded bean emergence and controlled soil movement less than did grassy fallows. This resulted in both increased yields and erosion losses for fields with older fallows. Conversely, correlations between yield and erosion for the cleared-field treatments showed an inverse relationship. Increased erosion losses were significantly correlated with decreased nitrogen mineralization for the labranza cero, windrow, and G. sepium mulch treatments (Table 4.11).

Modified stability analyses of erosion. The effect of environmental factors on soil degradation can be assessed using computations similar to those used to determine yield by environmental index interactions. Values obtained for soil erosion for each treatment were regressed against the mean values, across treatment, for soil erosion in each farm or environment (Figure 4.8b). A treatment by linear component of the environmental index for erosion was included as a source of variance in ANOVA (Table 4.12). Analyses of this component indicated that the environments included in the experiment may be separated into different recommendation domains based on susceptibility to erosion. Farms that had the lowest average soil losses due to erosion had the longest fallows. The cleared-field frijol espeque treatments produced high regression coefficients for erosion losses against the environmental index for erosion while the regression coefficients for both mulched-field treatments were less than one. Treatments with high regression coefficient values, exhibited significant regression relationships for soil

calcium against erosion losses. Treatments with low regression coefficient values did not exhibit significant relationships between environmental factors responsible for soil erodibility and soil losses due to erosion. For the mulched-field treatments, slopes obtained for soil losses due to erosion across environments were near zero.

As with the interpretation of yield data, treatments exhibiting regression coefficients close to zero were considered as stable with regard to soil erosion. Regression coefficients greater than one indicated treatments having a high environment by soil erosion interaction. The frijol tapado and labranza cero treatments had low regression coefficients, while the cleared-field frijol espeque treatments had high regression coefficients.

Technology Adoption

The significant yield increases that could be obtained by adopting frijol espeque during the veranero growing season may not influence farmers to abandon frijol tapado. Climatic and socioeconomic factors hinder the adoption of frijol espeque during this growing season. Continuous rainfall prevents land clearing by burning. Involvement in maize planting and coffee harvests also competes with labor needed for manual land clearing. Labor constraints may have a minimal effect on the adoption of labranza cero, however, since this method does not require the removal of residues from the soil surface. Detailed time-use studies conducted by the Organization for Tropical Studies have indicated that land preparation and planting for frijol tapado require 27.3 jornales per hectare (6 hour farm labor days) while frijol espeque require 39.6 jornales per hectare (Rosemeyer, personal communication). Based on these data, the same labor

inputs used to plant one hectare of frijol tapado could be used to plant only 0.69 hectares of labranza cero. However, based on yield data obtained in the current experiment, 0.68 hectares of land planted to labranza cero could produce the same yields as one hectare of frijol tapado (assuming that the same seeding rate was used in both practices).

In practice, labor constraints may be less than is indicated by a comparison of the total number of jornales required to plant beans. For frijol tapado, planting and the cutting of fallow growth are performed as an integrated operation. For labranza cero, cutting of the fallow growth is performed in advance of planting. Farmers who live close to the land they farm could intersperse fallow-cutting activities with the performance of other, more urgent farm activities. Consequently, during the critical planting period, the actual time required to plant beans to labranza cero would be less than the time required for the integrated cutting-and-broadcasting activities of frijol tapado.

Although no significant differences in weed incidence at harvest were observed between treatments, the costs incurred to obtain the observed levels of weed control were significantly different between treatments. All frijol espeque treatments included weed-control practices consisting of herbicide applications and one mid-season manual weeding. No weed-control practices were implemented for the frijol tapado treatment. Due to the mulch cover of the labranza cero treatment, weeding activities of this treatment required only one-third the time required to weed the cleared-field frijol espeque treatments. Calculated weed control costs, per hectare, for the bare-field frijol espeque, labranza cero, and frijol tapado treatments were 5,545 colones, 4,275 colones, and 0 colones, respectively. After subtracting costs for land-preparation, planting, and

harvesting, net returns on investment, per hectare, for these three planting practices were 3,405 colones, 5,315 colones, and 3,145 colones for bare-field frijol espeque, labranza cero, and frijol tapado, respectively (Table 4.13). These results indicate that labranza cero should be recommended when land is scarce in relation to labor. Alternatively, frijol tapado may be more profitable when labor is scarce in relation to land or when there is no money for the purchase of herbicides.

Land preparation labor values used for cleared-field frijol espeque included time required to manually remove residues from the field. If weather conditions permitted farmers to burn the residues, the time required to prepare and plant a hectare of frijol espeque for planting would be approximately equivalent to the time required to perform these operations in a field planted using labranza cero. This would increase the productivity of cleared-field frijol espeque. To estimate the future as well as the present productivity of cleared-field frijol tapado, however, erosion losses in this system should be assigned a discount rate based on decreasing productivity due to erosion. This discount rate would then be deducted against the profits of the system. Consequently, clear-field practices may exhibit high short-term but decreasing long-term profitability.

Conclusions

The Use of Modified Stability Analysis in the Analysis of On-Farm Experiments

The modified stability analysis method permits an examination of treatments under a wide range of environmental conditions and assessment of the effect of the environment

on various response factors. The farms used in the current experiments reflected this variability. The environments used ranged from farms with exposed rocks and incipient gully formation to soils with good tilth and little visible prior degradation.

The modified stability analysis procedure is inappropriate for obtaining precise determinations of treatment effects, because the large variability among farms confounds the effects of treatments and masks differences among the variables assessed. Use of only one treatment per location, furthermore, prohibits ANOVA of treatment responses within each environment. By-farm ANOVA provides more precise information on relationships between factors being assessed than do regression analyses. It also permits assessment of treatment responses to the specific environment of the experiment.

Conversely, MSA provides initial information with which to determine which environmental factors are affecting the variables of interest. It is also appropriate for on-farm research designed to test extension recommendations where severe tests of treatment response to field conditions are required. The variability among farms usually prohibits relationships obtained from one farm using ANOVA from being directly transferable to another farm. Analyses based on regression analyses over a range of environments may provide a better indication of treatment responses within the range of environments tested.

Treatments exhibiting the highest response to environmental indices, or those which are stable across environments, can be identified using MSA. By regressing measured environmental parameters for these treatments against yields, on a by-treatment

basis, the environmental factors responsible for the treatment by environmental response can be identified.

This research also showed that use of the MSA should not be limited to the analysis of yield responses to environment. It can also be used to assess the effect of environment on factors of site degradation. These studies also demonstrated that more precise information on the effects of environmental factors on assessed parameters can be obtained through the use of by-treatment rather than across-treatment analyses. Low correlations obtained for one treatment can mask significant relationships for another treatment when analyses are limited to the use of the average values obtained within each farm across treatment.

Despite its usefulness as a tool for predicting the response of treatments to a range of environmental conditions, the information obtained from MSA may not be able to be extrapolated beyond the conditions represented by the environments tested. The use of environments atypical of those usually used for cleared-field frijol espeque production resulted in these treatments exhibiting both high productivity and high responsiveness to environmental conditions. Under less favorable conditions, the high productivity of these treatments could probably not be maintained. These treatments also exhibited the highest level of soil degradation as indicated by significantly higher soil losses due to erosion, lower aggregate stability, and greatest penetrometer resistance.

Bean Planting Practices and Sustainability

Cleared-field frijol espeque planting methods produced higher yields than either the frijol tapado or the labranza cero treatments. These treatments also encouraged

greater soil degradation through soil erosion, removal of residue nutrients from the agroecosystem, and disruption of soil microbial processes. They were also more dependent on soil phosphorus than were the mulched field treatments. The frijol tapado and labranza cero treatments were able to obtain some of their phosphorus from the decomposition of mulch residues.

These results demonstrate that, as cleared-field frijol espeque methods are used more intensively, the potential for these treatments to produce higher yields will decrease. The high potential of these treatments for encouraging soil degradation was indicated by the steep response curve exhibited by cleared field treatments to the environmental index for erosion.

The mulch layer of the frijol tapado and labranza cero treatments retarded the onset of soil degradation by controlling soil erosion and protecting the soil against raindrop impact. Nutrient recycling within the ecosystem was also enhanced by not removing the fallow residues from the environment.

During the early stages of land degradation, increased productivity and agroecosystem degradation can exist simultaneously. Research and extension methods that select technology recommendations based primarily on yield assessments may result in farmers being encouraged to adopt farming methods that are not sustainable while discouraging farmers from using sustainable systems.

12 mm = 1000 meters

0 1000 2000 3000 4000 5000

METERS

Figure 4.1: Location of farms included in the study in relationship to Pejibaye. (Source of Map: Instituto Geográfico Nacional, 1975).

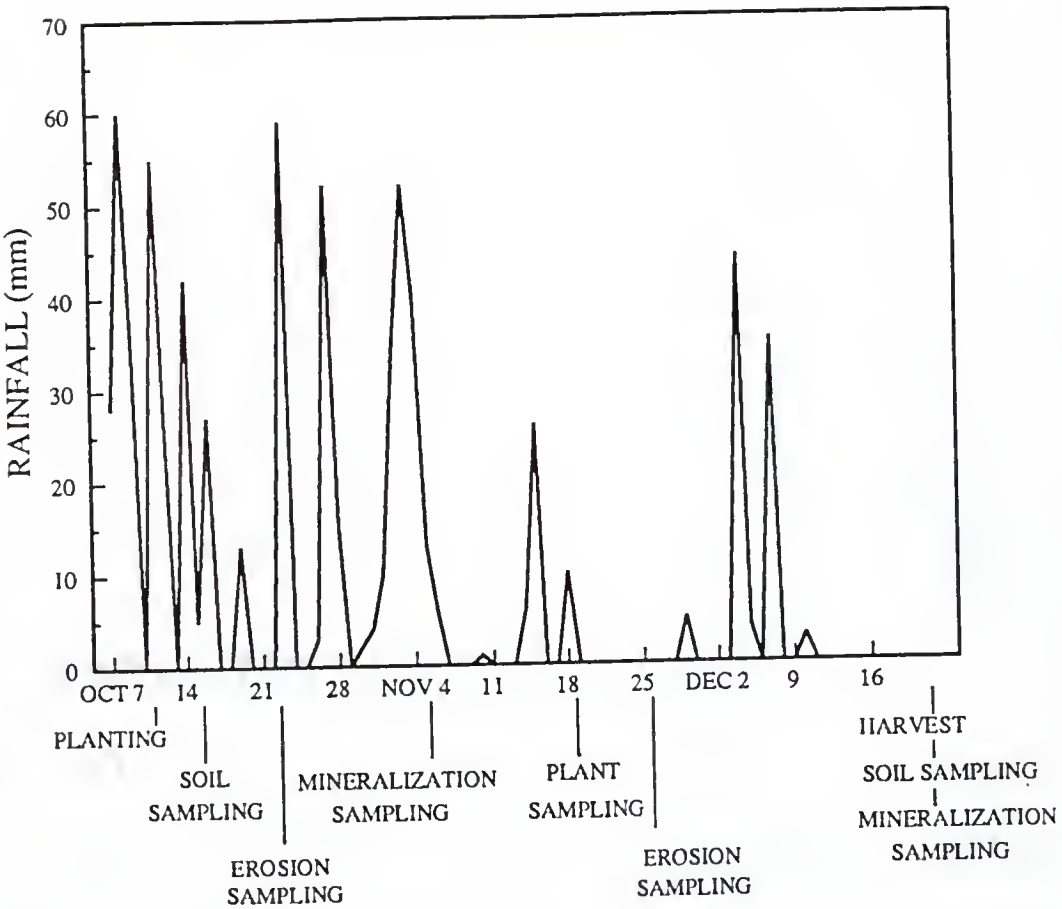


Figure 4.2: Rainfall, agricultural acitivities, and sampling times.

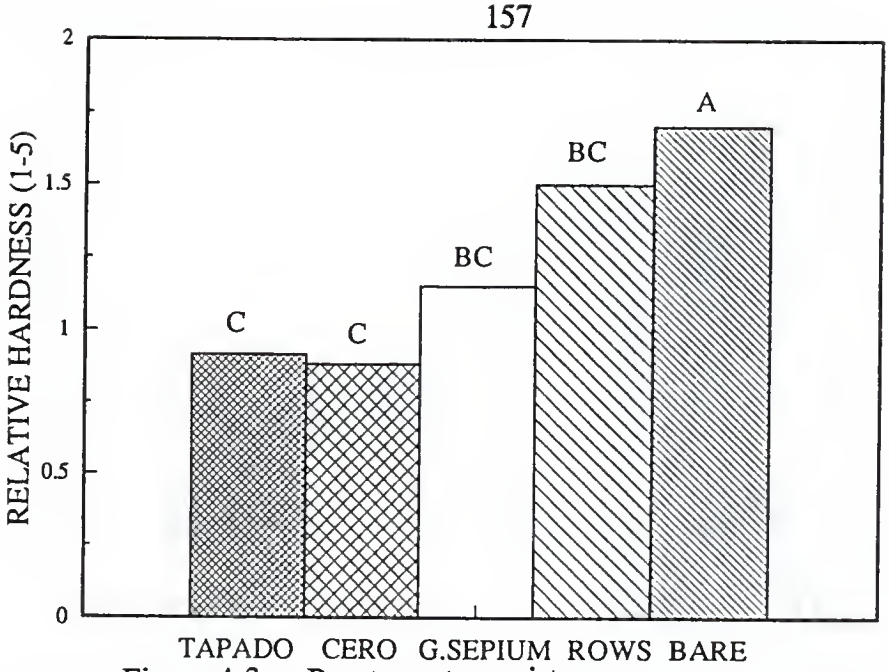


Figure 4.3a: Penetrometer resistance

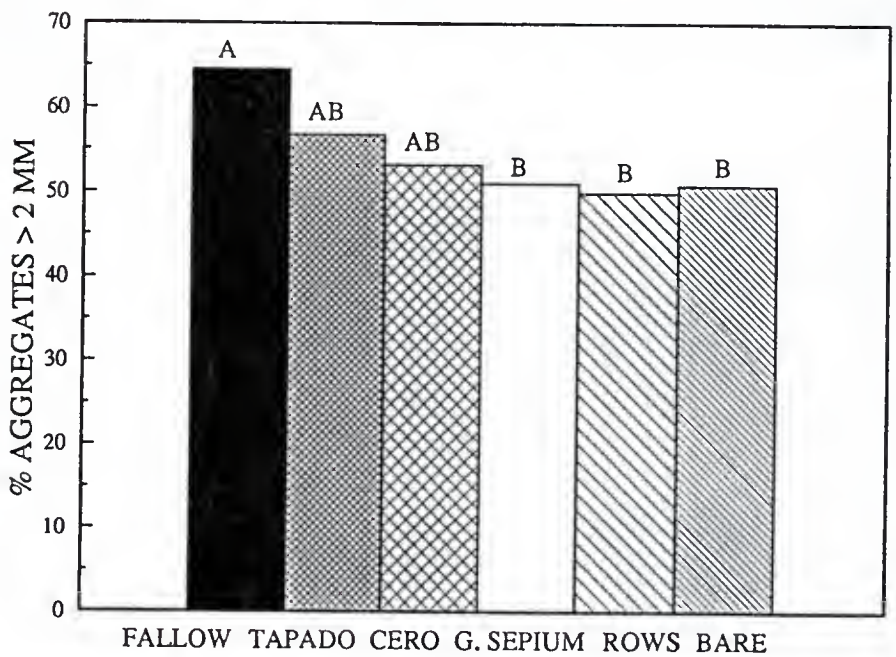


Figure 4.3b: Aggregate stability based on the percent of water stable aggregates > 2 mm.

Figure 4.3: Soil physical properties as affected by treatment.

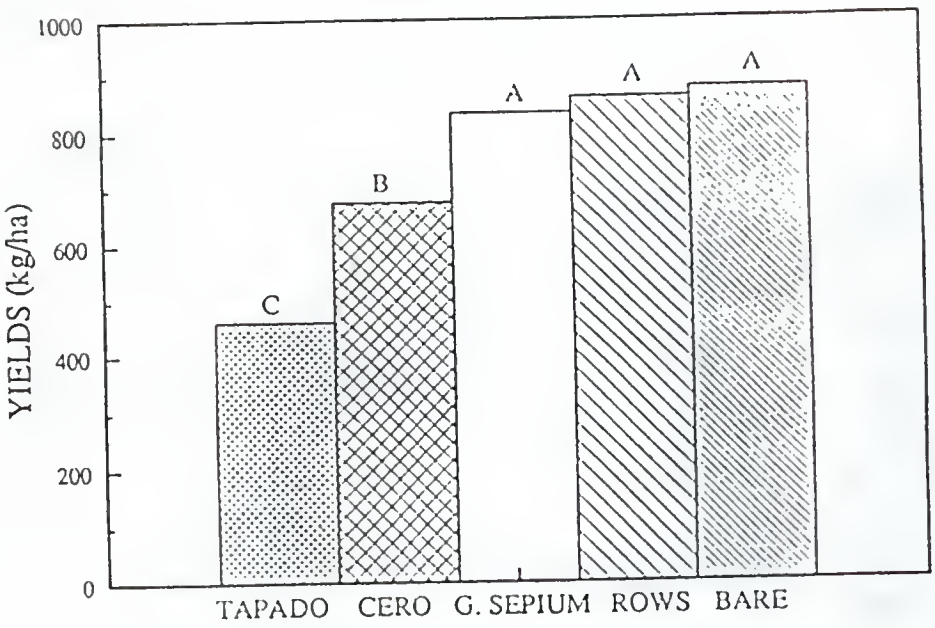
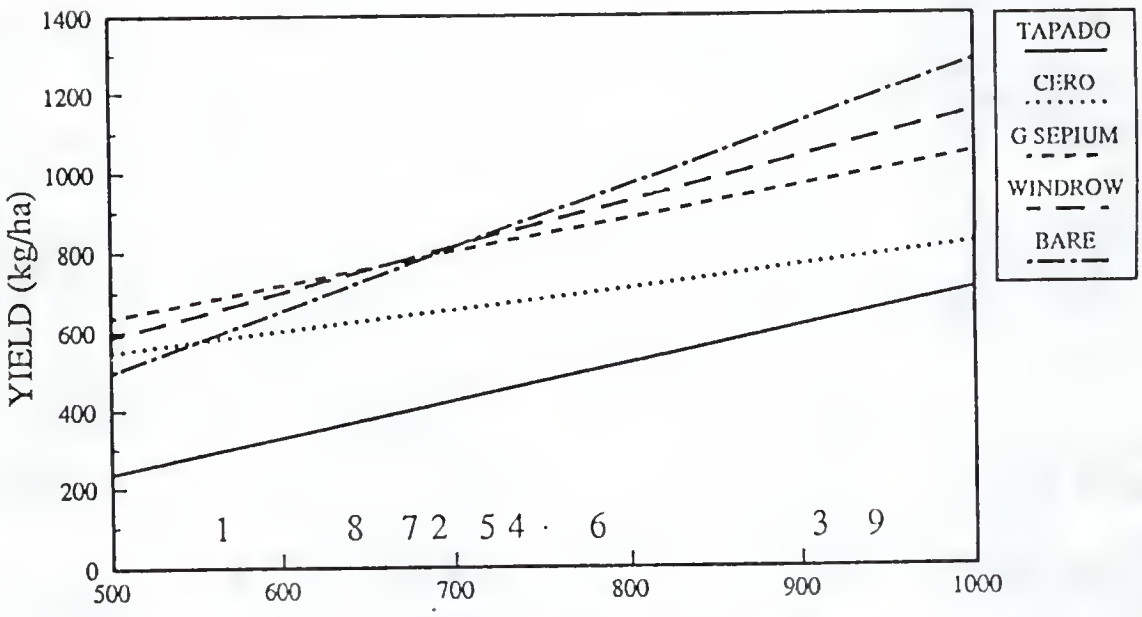


Figure 4.4a: Bean Yields as Analyzed by ANOVA



(Average yields for each farm included in the experiment are indicated by farm number)

Figure 4.4b: Bean Yields as Affected by Environment-MSA

Figure 4.4: Bean yields as analyzed by ANOVA and MSA.

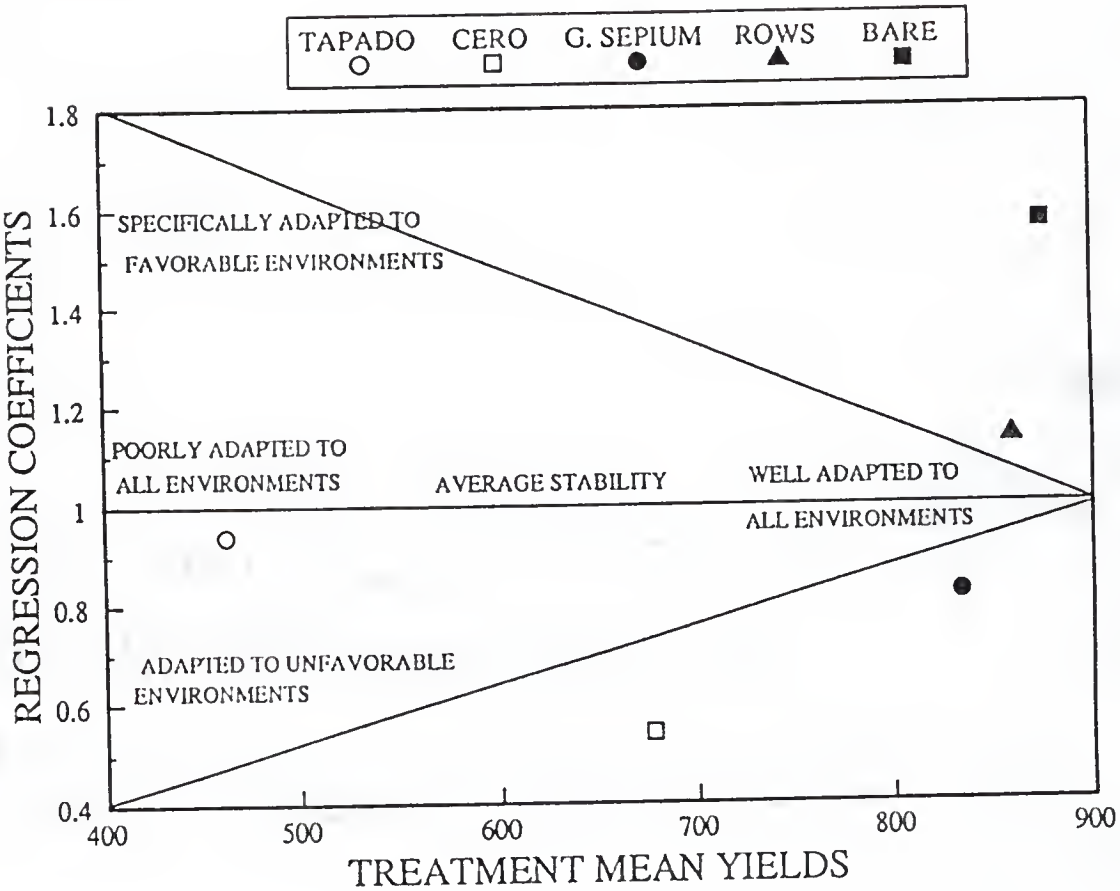


Figure 4.5: Classification of treatments based on the relationship between MSA regression coefficients and treatment mean yields. (Based on: Finlay and Wilkinson, 1963)

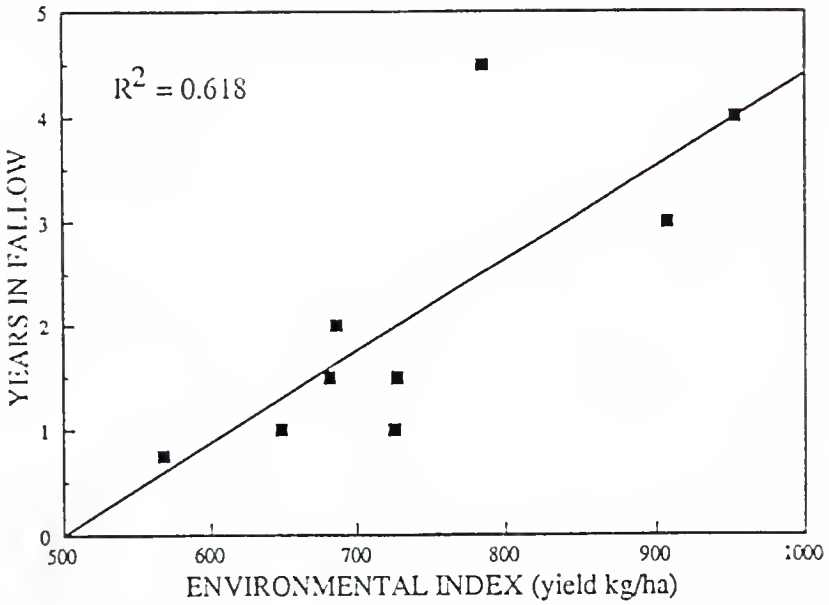


Figure 4.6a: Regression of fallow duration on the environmental index for all treatments.

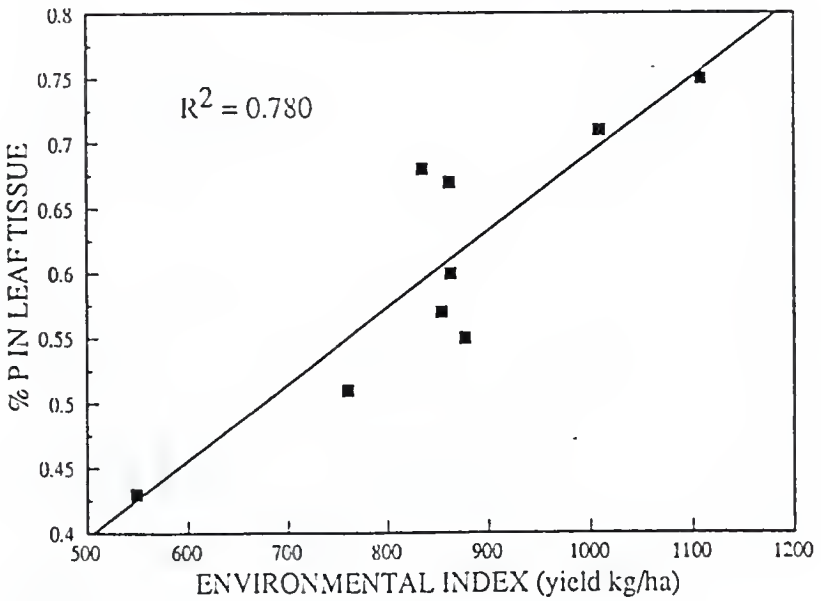


Figure 4.6b: Regression of phosphorus uptake on mean yields for cleared-field treatments in each farm.

Figure 4.6: Relationships of fallow duration and phosphorus uptake to environmental indices.

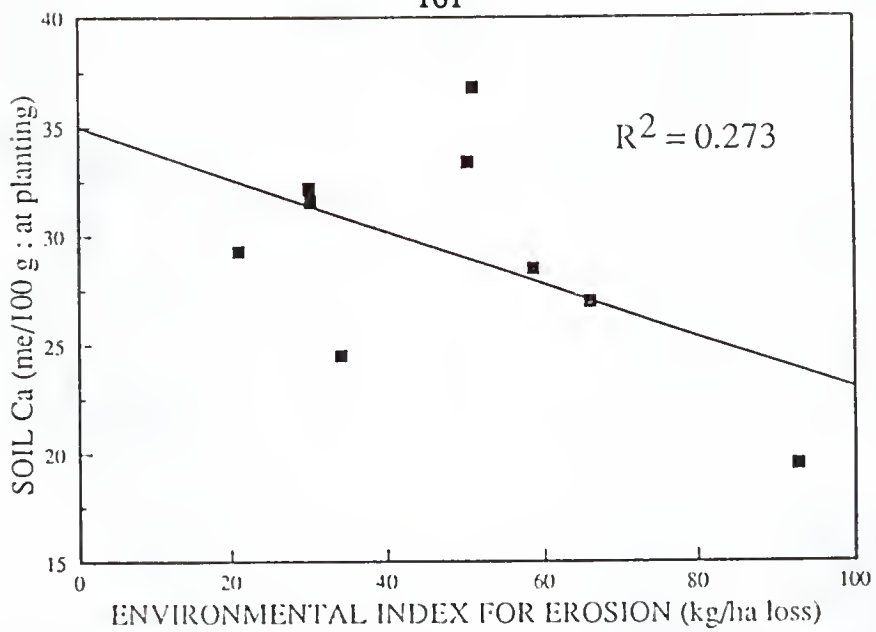


Figure 4.7a: Regression of mean values, in each farm, for soil Ca, at planting, on the environmental index for erosion.

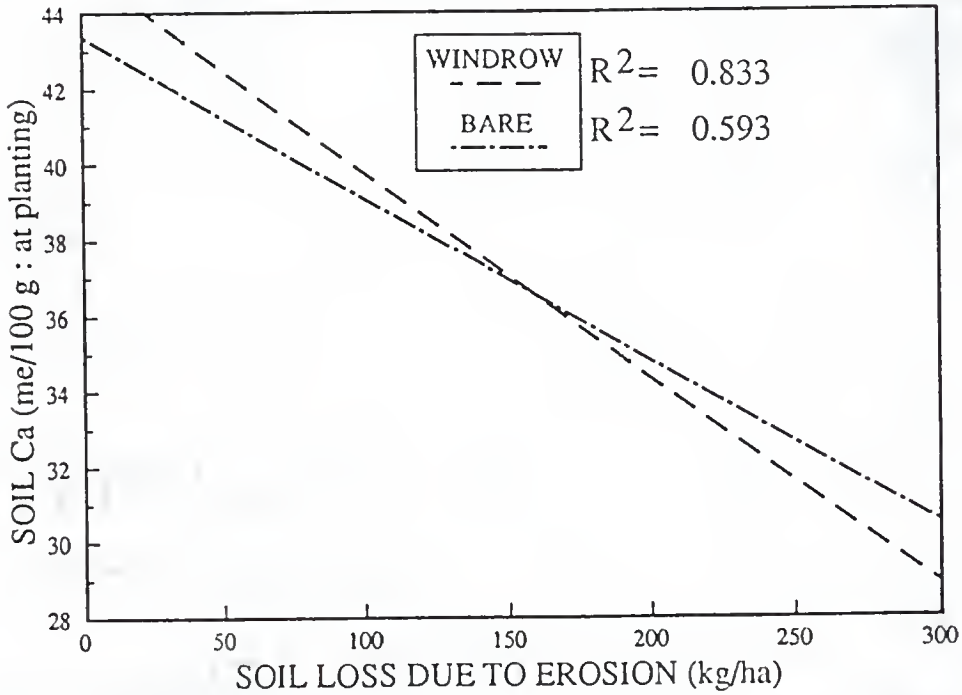


Figure 4.7b: Regression of soil calcium, at planting, on soil losses due to erosion: Bare-field and windrow frijol espeque treatments.

Figure 4.7: Regressions of soil calcium, at planting, on soil losses due to erosion.

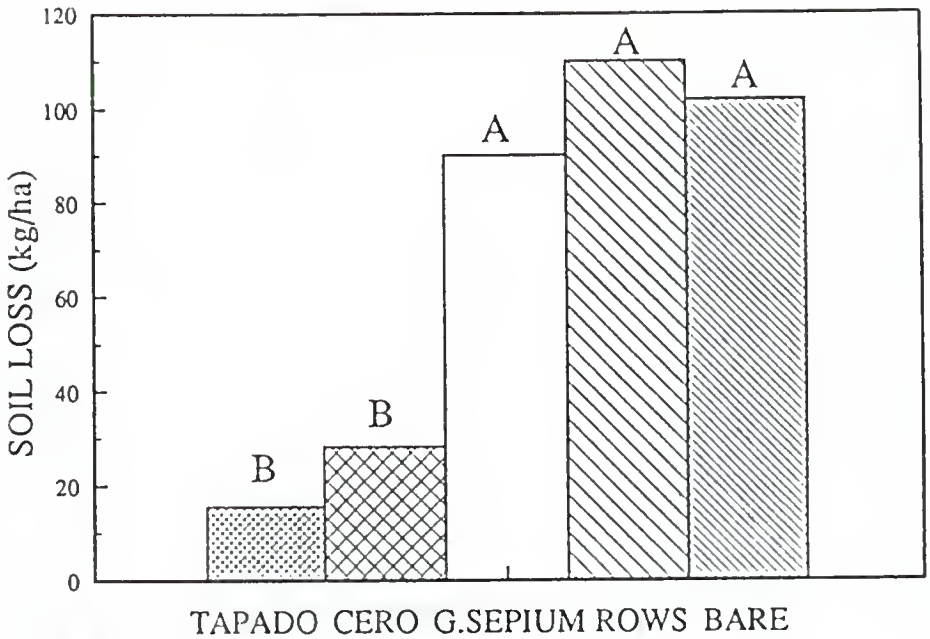


Figure 4.8a: Soil losses due to erosion: ANOVA.

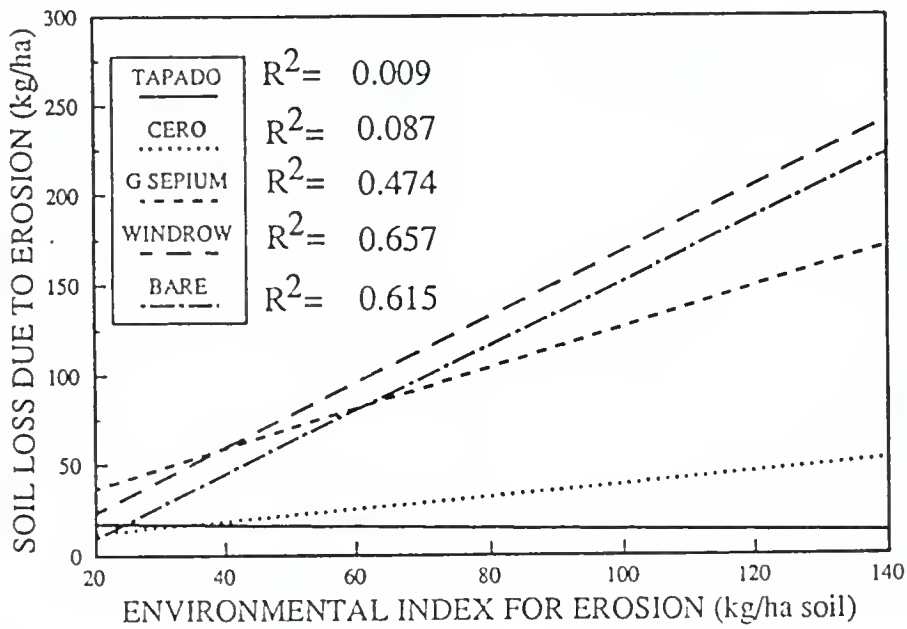


Figure 4.8b: Regressions between soil losses due to erosion, for each treatment in each environment, on the environmental index for erosion.

Figure 4.8: Soil losses due to erosion: Analyses based on ANOVA and MSA.

Table 4.1: Physical description, prior land use, and predominant fallow species of experimental farms.

FARM	ASPECT	SLOPE (%)	PRIOR LAND USE	FALLOW SPECIES[a]
1	ESE	72	4 years BMR[b], 1 year fallow	jaragua, guarumo, tora, tuete
2	SE	68	frijol tapado, 1 year BMR, 2 year fallow	jaragua, tora, tuete, chaperno
3	ESE	74	frijol tapado, 3 years fallow and occasional horse pasture	jaragua, mozote, tuete, helecho
4	S	71	3 years BMR, 1 year fallow	jaragua, zacate fuego, calinguero, platanilla, tora, tuete, helecho, churrite
5	S	68	annual frijol tapado	jaragua, zacate peludo, moriseco, platanilla, paira
6	S	67	4 years fallow and occasional horse pasture	guavo, targua, varilla negra, tora, achiotillo,
7	SW	85	3 years BMR, 1 year fallow	jaragua, zacata peludo, varilla negra, paira, churrite, churristate
8	WNW	71	annual frijol tapado	jobo, jaragua, tarquesa, zacate peludo, churrite, platanilla, churristate
9	WNW	83	3 years fallow and occasional horse pasture	guavo, achiotillo, jaragua, navajuela tuete, mastuerso, helecho

a. Scientific names for plant species are listed in Table 2.2.
b. Bean-maize rotation (two crops/year).

Table 4.2: Soil characteristics of experimental farms at planting.

FARM	CLAY (%)	SAND (%)	SILT (%)	pH	OM (%)	P[a] (ppm)	K[a] (me $100g^{-1}$)
1	30.0	28.2	41.8	6.8	4.4	7.8	1.37
2	15.6	37.9	46.5	7.0	5.9	93.5	1.92
3	8.8	41.6	49.6	6.8	5.5	63.0	1.24
4	25.2	23.2	51.6	6.8	5.5	5.4	1.15
5	16.8	39.6	43.6	6.7	6.8	104.2	2.03
6	31.2	20.3	48.5	6.5	6.3	9.0	1.50
7	23.2	30.6	46.2	6.7	6.1	45.1	1.69
8	21.6	29.0	49.4	6.9	6.3	6.0	2.06
9	11.6	34.7	53.7	7.0	5.1	25.8	1.55

a. Soil nutrients extracted with Bray II solution.

Table 4.3: Land preparation and planting treatments installed on the experimental farms.

TREATMENT	LAND PREPARATION AND PLANTING METHOD
Tapado	Bean seeds broadcast-planted into uncut vegetation. Following planting, vegetation cut to soil level, chopped into small pieces, and left in place as a mulch. No herbicides used.
Labranza cero	Vegetation chopped to height of 20 cm and treated with Glyphosate (2 liter ha^{-1}) 15 days prior to planting. Paraquat (2 liters ha^{-1}) applied one day after planting.
Espeque-with Gliricidia sepium mulch	Vegetation chopped at soil level prior to planting and removed from the plot. A combination of herbicides, Prowl (2 liter ha^{-1})+ Terbacil (1.2 kg ha^{-1}) was applied one day after planting. Fresh Gliricidia sepium leaves (1.23 tons ha^{-1} dry weight) were placed on the soil surface immediately following herbicide application.
Espeque-with windrows	Vegetation chopped at soil level and placed into windrows, 5 meters apart, along the contours of the field. A combination of herbicides, Prowl (2 liter ha^{-1}) + Terbacil (1.2 kg ha^{-1}) was applied one day after planting.
Espeque-bare soil	Vegetation chopped at soil level prior to planting and removed from the plot. A combination of herbicides, Prowl (2 liter ha^{-1}) + Terbacil (1.2 kg ha^{-1}) was applied one day after planting.

Table 4.4: Soil nutrients and organic matter at planting.

Soils 0-15 cm, at planting

TREATMENT	OM (%)	PHOSPHORUS (ppm)	POTASSIUM (me $100g^{-1}$)	CALCIUM (me $100g^{-1}$)
Bare-field frijol espeque	5.9a	39.9a	1.63abc	27.8a
Frijol espeque with windrows	5.7a	44.8a	1.75ab	28.9a
Frijol espeque with G. sepium	5.9a	41.9a	1.27c	30.8a
Labranza cero	5.6a	45.4a	1.97a	27.9a
Frijol tapado	5.6a	27.9a	1.44bc	29.8a
$F_{treatment}$	3.2	0.75	3.30	1.1

Soils 15-30 cm, at planting

TREATMENT	OM (%)	PHOSPHORUS (ppm)	POTASSIUM (me $100g^{-1}$)	CALCIUM (me $100g^{-1}$)
Bare-field frijol espeque	4.4a	19.2a	1.35a	28.4a
Frijol espeque with windrows	4.5a	21.9a	1.29ab	27.8a
Frijol espeque with G. sepium	4.1a	18.2a	1.03b	26.8a
Labranza cero	4.4a	24.9a	1.26ab	27.9a
Frijol tapado	4.1a	15.1a	1.10ab	31.4a
$F_{treatment}$	1.25	1.26	2.17	1.33

Table 4.5: Soil nutrients and organic matter at harvest.

Soils 0-15: at harvest

TREATMENT	OM (%)	PHOSPHORUS (ppm)	POTASSIUM (me $100g^{-1}$)	CALCIUM (me $100g^{-1}$)
Bare-field frijol espeque	7.3a	43.3a	1.79a	30.7a
Frijol espeque with windrows	6.5a	32.5a	1.89a	26.0ab
Frijol espeque with G. sepium	6.7a	40.7a	1.36b	24.4b
Labranza cero	6.6a	45.3a	1.76a	29.5ab
Frijol tapado	6.4a	27.2a	1.25b	30.9a
$F_{treatment}$	0.84	1.00	5.59	2.37

Soils 15-30: at harvest

TREATMENT	OM (%)	PHOSPHORUS (ppm)	POTASSIUM (me $100g^{-1}$)	CALCIUM (me $100g^{-1}$)
Bare-field frijol espeque	5.34ab	28.18a	1.26a	28.63a
Frijol espeque with windrows	5.11ab	19.09a	1.23a	26.09a
Frijol espeque with G. sepium	5.36ab	25.13a	0.97b	26.07a
Labranza cero	5.80a	31.81a	1.33a	29.66a
Frijol tapado	4.66b	15.64a	0.95b	33.19a
$F_{treatment}$	1.38	1.60	4.60	1.73

Table 4.6: Nitrogen availability as determined by nitrogren mineralization and microbial biomass.

TREATMENT	Nitrogen Mineralization[a] (0-28 DAP) (mg g^{-1} soil)	Nitrogen Mineralization[a] (29-80 DAP) (mg g^{-1} soil)	Microbial Biomass N[b] (Harvest) (mg g^{-1} soil)
Bare-field frijol espeque	20.1ab	34.3ab	82.9a
Frijol espeque with windrows	16.4b	29.7ab	76.8a
Frijol espeque with G. sepium	15.9b	40.6a	73.9a
Labranza cero	25.5a	34.3ab	81.6a
Frijol tapado	9.7c	24.8b	72.6a
$F_{treatment}$	8.51	2.72	0.60

a. Nitrate nitrogen.
b. Ninhydrin reactive nitrogen.

Table 4.7: Nodualation by rhizobia, nitrogen uptake, and phosphorus uptake.

TREATMENT	NODULATION (number)	N UPTAKE (%)	P UPTAKE (%)
Bare-field frijol espeque	47ab	4.68a	0.62ab
Frijol espeque with windrows	52ab	4.65a	0.60b
Frijol espeque with G. sepium	68a	4.69a	0.61ab
Labranza cero	45ab	4.68a	0.68a
Frijol tapado	29b	4.66a	0.67ab
$F_{treatment}$	7.59	4.74	8.50

Table 4.8: Correlation coefficients, by treatment, between yields and soil, environmental, and nutrient uptake factors

	R	PROB > F
BARE-FIELD FRIJOL ESPEQUE		
Weed incidence[b]	0.645	0.0607
Phosphorus in leaf tissue	0.865	0.0026
Length of fallow	0.845	0.0041
FRIJOL ESPEQUE WITH WINDROWS		
Phosphorus in leaf tissue	0.9217	0.0004
Percentage of clay in the soil[b]	0.6971	0.0369
FRIJOL ESPEQUE WITH G. SEPIUM		
Phosphorus in leaf tissue	0.558	0.1181
Length of fallow	0.5167	0.1543
Percentage of clay in the soil[b]	0.5532	0.1224
LABRANZA CERO		
Weed incidence[b]	0.5967	0.0898
Soil loss due to erosion	0.7468	0.0208
Length of fallow	0.6804	0.0437
FRIJOL TAPADO		
Length of fallow	0.6975	0.0367

a. All coefficients are positive unless otherwise indicated.
b. negative coefficient.

Table 4.9: Analysis of variance of yield including environmental index by treatment.

SOURCE	DF	TYPE I SS	MEAN SQUARE	F VALUE	Pr > F
Farm	8	599920.2	74990.0	4.35	0.0017
Treatment	4	1107554.9	276888.7	16.08	0.0001
EI x Treat	4	71492.6	17873.1	1.04	0.4053
Error	28	482254.2	17223.4		
Corr. Total	44	2261221.9			

Table 4.10: Correlation and regression coefficients for treatment yields against environmental index.

TREATMENT	R	R^2	Prob > F
Bare-field frijol espeque	1.57	0.9360	0.0001
Frijol espeque with windrows	1.13	0.3928	0.0709
Frijol espeque with G. sepium	0.82	0.5072	0.0313
Labranza cero	0.54	0.4447	0.0498
Frijol tapado	0.94	0.5044	0.0320

Table 4.11: Correlation coefficients, by treatment, between erosion and soil factors.

	R	PROB > F
BARE-FIELD FRIJOL ESPEQUE		
Total cations, at planting	0.7703	0.0253
FRIJOL ESPEQUE WITH WINDROWS		
Total cations, at planting	0.9126	0.0006
N mineralization (2nd sampling)	0.7221	0.0431
FRIJOL ESPEQUE WITH G. SEPIUM		
Total cations, at planting	0.1189	0.7606
N mineralization (1st sampling)	0.6649	0.1032
Length of fallow	0.5724	0.1072
LABRANZA CERO		
Yields[b]	0.7468	0.0208
N mineralization (1st sampling)	0.5846	0.0983
Length of fallow[b]	0.7192	0.0290
FRIJOL TAPADO (no significant correlations)		

a. All coefficients are negative less otherwise indicated.
b. positive coefficient.

Table 4.12: Analysis of variance of erosion including environmental index by treatment.

SOURCE	DF	TYPE I SS	MEAN SQUARE	F VALUE	Pr > F
Farm	8	7159.67	894.96	2.13	0.0685
Treatment	4	15916.99	3979.25	9.45	0.0001
EI x Treat	4	3943.08	985.77	2.34	0.0804
Error	27	11370.47	421.13		
Corr. Total	43	38390.21			

Table 4.13: Economic costs and returns from bare-field frijol espeque, labranza cero, and frijol tapado.

	BARE-FIELD FRIJOL ESPEQUE	LABRANZA CERO	FRIJOL TAPADO
Herbicide cost[a]	1870	2175	0
Herbicide application[b]	525	1050	0
Mid-season manual weeding	3150	1050	0
Total weed control costs	5545	4275	0
Land-preparation and planting[c]	24500	13860	9555
Harvest costs[c]	9100	9100	9100
Total costs	39145	27235	18655
Value of beans harvested[d]	42550	32550	21800
Net returns	3405	5315	3145

a. All costs are reported in colones ($1 US = 107 colones, 1-1-91).
b. Calculations based on the number of jornales (6 hour farm labor days) required to complete the activity. Each jornal is valued at 350 colones.
c. Calculations based on studies conducted by the Organization for Tropical Studies (Rosemeyer, personal communication).
d. Calculations based on average bean yields obtained for each treatment in the current experiment. Yields were valued at 50 colones per kilogram.

CHAPTER 5
THE EFFECTS OF LAND FALLOWING, LAND PREPARATION METHODS, AND PHOSPHORUS FERTILIZATION ON FRIJOL ESPEQUE BEAN YIELDS AND SOIL DEGRADATION

Introduction

To be sustainable, bean farming practices should be profitable, produce stable yields with stable levels of inputs, and not promote soil degradation. Results from previous experiments conducted in conjunction with this research showed that higher yields could be obtained from cleared-field frijol espeque compared to labranza cero or frijol tapado. Soil degradation, however, was greater in cleared-field frijol espeque treatments compared to labranza cero or frijol tapado treatments. This was evidenced by increased soil losses due to erosion, higher penetrometer resistance, and decreased aggregate stability. Besides controlling soil degradation, mulched-field practices also decreased weed and web blight infestations and increased nitrogen availability due to mineralization.

Extended land fallowing prior to cultivation decreased the adverse impact of cleared-field frijol espeque on soil degradation. Based on modified stability analyses, cleared-field frijol espeque had increasingly higher yields compared to labranza cero as phosphorus availability and the duration of fallow-time prior to planting increased. In the environments which produced the lowest overall yields, the two bean planting

practices produced similar yields. Frijol espeque and labranza cero are typically planted in a continuous cultivation rotation with maize, rather than in conjunction with a fallow rotation as was used in the previous experiments. The experiments described in this chapter were designed to assess the interactive effects of land fallowing and land-preparation practices on bean yields and soil degradation.

Effects of Residue Burning and Mulching on Nutrient Availability and Soil Degradation

Frijol espeque typically is practiced on steeply sloping land that has not been plowed. Residues remaining from the previous growing season and the fallow dry season are chopped with a machete prior to planting. The chopped residues may either be manually removed from the field, burned in place or in piles, or left as a mulch on the soil surface. Interviews indicated that most farmers prepare their land for frijol espeque planting by burning the residues. Reasons given by farmers for preferring this land-preparation practice included: low labor costs, ease of planting and agrochemical application within a cleared field compared to a mulched field, the availability of plant nutrients from residue ash, and the belief that burning controls slug infestations.

The Costa Rican Ministry of Agriculture is presently encouraging farmers not to burn crop residues, but instead to leave the residues on the soil surface as a mulch. Mulches associated with fallows have been shown to be effective in controlling erosion, weed regrowth, and the dissemination of a soil-borne fungal disease, web blight. However, mulches limited to maize and weed residues produced during a typical

continuous cropping bean-maize rotation provide insufficient soil coverage to act either as a soil conservation technique or as a pest control measure.

Availability of nutrients from residues due to decomposition is slower than through burning. Furthermore, depending on the C:N ratio of the residues, the presence of soil surface residues can result in immobilization of nutrients in the soil solution. Results from laboratory studies showed that, at 14 days after the onset of incubation, surface-placed maize residues decreased nitrogen mineralization to approximately 75% of that occurring in unamended soils (Smith and Sharpley, 1990). Wheat and oat straw amendments exhibited mineralization rates comparable to those for unamended soils after 14 days.

In contrast to decomposition processes, burning of residues immediately releases nutrients to the soil system. The availability of nutrients from residue burning is dependent on the quantity and quality of the residues as well as the temperature and completeness of the burn. Incomplete, lower-temperature burns release fewer bases but higher concentrations of nitrogen and phosphorus to the soil than higher-temperature (temperatures $>400^{\circ}$ C), more complete burns (Ewel et al., 1981; Ramakrishnan and Toky, 1981; Andriesse and Schelhaas, 1987a). Kutiel and Shaviv (1989) reported that 34% of the soil nitrogen was lost during burns at 250° C, whereas 86% of the nitrogen was lost during burns at 600° C. They also reported that almost twice as much phosphorus was released from soils burned at the lower temperature compared to soils burned at the higher temperature.

Lal (1987b) argued that the advantages of rapid nutrient release due to burning are offset by nutrient losses of almost 50%, the volatilization of organic matter during burning, and soil erosion resulting from the subsequent exposure of burned soils to raindrop impact. In contrast to burning, retention of mulches on the soil surface resulted in decreased soil losses and water runoff due to erosion, decreased soil temperatures, and increased water infiltration and hydraulic conductivity as mulch application rates increase from 2 to 12 tons ha^{-1} (Lal et al., 1980). Ayanaba et al. (1976) reported that for fields cleared from fallow, the retention of maize residues on the fields resulted in less loss of carbon and nitrogen compared to cleared-fields.

Effect of Fallowing and Land Preparation Phosphorus Availability

Phosphorus is commonly reported as yield-limiting in soils of tropical South and Central America (Arnason et al., 1982; Sanchez et al., 1982). For temperate soils, McGill and Cole (1981) described nitrogen and phosphorus cycles as operating independently with the nitrogen cycle functioning through biological mineralization and the phosphorus cycle functioning through biochemical mineralization. In weathered, tropical soils, a large proportion of the inorganic phosphorus fraction is either in unavailable forms or has previously been removed from the profile. Consequently, organic phosphorus in soil organic matter and residues forms a significant portion of the labile pool of soil phosphorus (Duxbury et al., 1989). The mineralization of organic phosphorus is determined by factors affecting microbial growth including temperature, moisture content, and nutrient availability. In English woodland soils, the availability

of organic phosphorus was related to soil pH and extractable Ca (Harrison, 1982). Cole and Heil (1981) reported that when ecosystems are at steady state, the amounts of biologically active nitrogen and phosphorus will be in balance. In agreement with these results, Adams et al. (1989) reported that estimates for available inorganic and organic nitrogen in a forest soil from Tasmania were highly correlated with estimates for organic phosphorus availability.

Fallowing and mulching also influence the availability of phosphorus. Under shifting cultivation, Ramakrishnan and Toky (1981) reported a depletion of available phosphorus during short-term fallows up to 5 years, with a subsequent rapid build-up of phosphorus occurring as the fallow time increased from 10 to 50 years. In weathered tropical soils, the conservation of phosphorus and calcium from the decomposition of organic residues is enhanced through the uptake of these nutrients by superficial tree root-mats (Stark and Jordan, 1978). In accordance with these results, Andriesse and Schelhaas (1987b) reported that phosphorus availability was twice as large for a Malaysian soil permeated with small surface-feeding roots than it was for a Sri Lankan soil dominated by a deep rooting system. Under continuous cultivation, higher extractable phosphorus, organic phosphorus, and phosphatase activity were measured in no-tillage plots compared to conventionally tilled plots (Haynes and Knight, 1989).

Based on this information, phosphorus availability should be enhanced by both fallowing and mulching. Mulches resulting from land fallowing should control weed and web blight infestations more effectively than mulches derived from a bean-maize rotation. Short-term availability of nutrients from residues will be enhanced by burning, while

long-term recycling of nutrients within the agroecosystem will be enhanced by mulching. The availability of nitrogen from burned residues is dependent on the temperature and completeness of the burn. The availability of nitrogen from decomposition is dependent on the chemistry of the residues and the availability of nutrients and water for the micro-organisms involved in the decomposition processes.

Materials and Methods

Treatment Installation

Farms. To determine the effect of prior land use on bean growth and soil degradation, a set of experiments was conducted on two farms. Farm I was continuously cropped with a bean-maize rotation for 3-4 years, then fallowed for three years. Farm II had been used for continuous bean and maize production for at least eight years. The location of the farms in relation to Pejibaye is shown in Figure 5.1. Experimental farms chosen had similar slopes (Table 5.1). Predominant plant species identified in the fallow vegetation of the experimental farms are listed in Table 5.1. Soil nutrients at planting, for both farms, are given in Table 5.2.

Treatments. Three replicate blocks of three land-preparation treatments were installed on each farm. Each block measured 18 m wide by 15 m long. The land-preparation treatments compared were: land clearing by burning, land clearing by piling residues in a windrow along the contour line in the center of each plot, and labranza cero. Labranza cero was prepared by chopping cut plant residues into short pieces, and

leaving them in-place on the soil surface. Treatments were assigned randomly within each block.

Each land-preparation treatment plot was vertically subdivided into two subplots: no P and 60 kg ha^{-1} P as triple super-phosphate. Each subplot was vertically subdivided into two sub-subplots: with and without rhizobium inoculation. A combination of rhizobia inoculant strains 436 and 477 (obtained from the laboratory of O. Acuña, UCR) was applied, as a thick paste, to seeds at the time of planting.

Each main plot measured 5 m wide by 15 m long. Each rhizobia sub-subplot had a width of 1.25 m. A 1.5 m wide buffer strip was left between each block of treatments.

Land preparation, planting and field maintenance. Plant growth, within each block, was cut to the soil surface during the first week of April, 1991. In the burned-field treatments, slightly damp residues were burned on April 18 using a low temperature burn. On April 25, paraquat herbicide was applied to all treatments at the rate of 2 liters ha^{-1}. On May 4, glyphosate herbicide was applied at a rate of 0.5 liter ha^{-1} to all plots. All plots were planted on May 12 with certified seeds of the variety "Talamanca". Seeds were planted using a dibble-stick at a rate of 2 seeds per hill, with 25 cm between hills and 50 cm between rows (five lines of plants per sub-subplot). A germination test, conducted prior to planting, indicated a germination rate of 99+%.

One day prior to planting, a molluscacide (Agrocom B5% Cebo) was broadcast-applied into each plot at a rate of 12.5 kg ha^{-1}. At planting, 20 kg ha^{-1} N as urea and P, according to treatment, were applied with a dibble stick approximately 8 cm to the side of the planting hole. On May 28, Benlate fungicide was applied to all plots of Farm II.

All plots were manually weeded 2 weeks after planting, and plots were harvested on July 27.

Soil Analyses

Nitrogen and phosphorus availability. Nitrogen mineralization was determined using a modification of the sequential soil core method described by Raison et al. (1987). Soil samples were taken on May 6, May 22, June 6, and July 27. During the first three sampling periods, seven PVC tubes (4 cm internal diameter by 15 cm long) were hammered into each subplot along a vertical transect. Each tube was immediately removed from the soil, both its top and bottom were covered with heavy plastic, and then the entire tube assemblage was placed in a polyethylene bag. The bagged tube was immediately reburied, without reversal of soil horizon orientation, in the same hole from which it was removed. Ash and plant residues were placed over the buried tubes in the burned and labranza cero treatments, respectively. Soil samples, to the 15 cm depth, were taken immediately to the side of each buried tube and bulked within each sub-plot. On May 22, June 6, and July 28, buried tubes were removed from each subplot and the soil removed from the tubes. Soil from all tubes collected from a given subplot was bulked. Ten gram subsamples from all initial and incubated soil samples were extracted with 50 ml of 2 N KCl within eight hours of sampling. Filtered extracts were stored at 5° C until analysis. The concentration of nitrate nitrogen in extracts was determined using a Technicon AutoAnalyzer (Technicon, 1978). Nitrogen mineralization was determined by subtracting nitrate values for the unincubated samples from nitrate values for the incubated samples.

At each sampling period, subsamples from the bulked and unincubated soil samples were air-dried, ground to pass a 20 mesh sieve, and analyzed for P using the method of Olsen and Sommers (1982). Unincubated samples taken on May 6 and July 28 were analyzed for pH, using a 2:1 soil to water paste, and for organic matter, using a Walkley-Black method (Nelson and Sommers, 1982).

Soil microbial biomass was assessed using subsamples of the unincubated, bulked soil samples. Within 8 hours of sampling, 15 g of fresh soil were placed in capped "core-pak" canning-type jars having a volume of 120 ml. One ml of 99% pure chloroform was added to each jar. The jars were then capped tightly, shaken, and incubated at room temperature for 5 days. Following incubation, all jars were opened and aerated overnight and ammoniacal nitrogen was extracted with 80 ml of 2 N KCl. Filtered extracts were stored at 5° C until analysis for ninhydrin-reactive nitrogen (Amato and Ladd, 1988).

Erosion assessments. Soil losses due to erosion were determined using run-off plots of 15 m length. Runoff from the plot was isolated by a sheet metal barrier embedded in the soil at the upper edge of each plot, and by trenches dug along the vertical edges of each plot. The collection trough was constructed of heavy-duty plastic attached to the ground by metal staples (Figure 5.2). The capacity of the runoff trough was approximately 220 liters. Runoff plots were installed in each treatment plot on April 21. Soil runoff was collected on May 4, May 18, June 1, and July 26. Collected samples were dried and weighed. Subsamples were ground to pass through a 20-mesh sieve and analyzed for organic matter and Olsen extractable P using the methods described above. Since each erosion plot encompassed all subplots, the effects of

fertilizer and rhizobia treatments were negated. To evaluate erosivity, rainfall amounts and intensities in Pejibaye were recorded throughout the growing season.

Soil physical properties. Soil penetrometer and soil bulk density analyses were made at midseason and at harvest, respectively. Soil bulk density was measured using tubes 5 cm long with an internal diameter of 4.2 cm. Penetrometer analyses were made using a pocket penetrometer, with relative hardness values ranging from 0 to 5. Bulked soil samples, to the 0-2 cm depth, were taken at planting for aggregate stability analyses. The minimally disturbed soil samples were air-dried and sieved according to a modified method of Yoder (1936) and Kemper and Chapil (1965).

Nutrient inputs from residues and ash. Above-ground biomass was sampled in triplicate for each plot prior to plot clearing or burning. All residues within a 0.25 m^2 quadrant were collected, dried at 70° C, and weighed (Anderson and Ingram, 1989). Subsamples were ground using a Wiley mill and analyzed for nitrogen and phosphorus. Phosphorus was determined, using an AutoAnalyzer, on ground material that had been ashed and then dissolved in 100 ml of 10 N HCl. Nitrogen content was determined via a Kjeldahl digestion followed by colorimetric assessment using a spectrophotometer. Ash in the burned-field treatment was collected and analyzed using the same methods as for the plant residues.

Soil moisture. In conjunction with midseason plant analyses, the gravimetric water contents of soils in Farm I were compared at the land-preparation treatment level.

Symbiotic Relationships with Bean Roots

Sixteen plants per sub-subplot (representing 8 hills/sub-subplot) were collected 29 days after planting. The above-ground portions of the plants were dried at 70° C and weighed. Dried plants were then ground using a Wiley mill and assayed for nitrogen and phosphorus using the methods described above. The nodules on each root were counted and the average number of nodules per plant in each sub-subplot was determined.

Harvest Analyses

Bean yields. For each sub-subplot, all bean plants in a section two hills wide by ten rows long were harvested. The number of plants harvested was counted and beans harvested from these plants were dried and weighed. To assess seed quality, the percentage of damaged seeds in duplicate, randomly selected 50-seed subsamples was determined.

Web blight and weed infestation. Following harvest, weed infestation was assessed in triplicate for each subplot. For each assessment, all weeds within a 0.25 m^2 quadrant were collected, dried at 70° C, and weighed. Web blight infestation was visually determined based on the percentage of plants collected for harvest analyses that were infested.

Labor Inputs

All plots were weeded 2 weeks after planting. In addition, all plots in Farm II received one application of a fungicide. Time required to weed and apply the fungicide to each treatment plot was carefully recorded. Average per-plot labor inputs (in minutes)

for each land preparation treatment were converted into jornales (six-hour labor days) per hectare of labor use.

Statistical Design

Treatments were replicated three times on each farm. Erosion was analyzed using an RCB design. Subplot and sub-subplot treatment effects were determined for each farm separately and also across farms. Subplot factors, for individual farms, were analyzed using a split-plot design while sub-subplot factors were analyzed using a split-split plot design. In determinations of treatment effects across farms, main plots were considered as crossed between farms. Statistical analyses were conducted using the GLM procedure of SAS (SAS, 1985).

Results

Rainfall

Rainfall during the growing season, as recorded in the center of Pejibaye, was 396 mm. Four rainfall events had intensities greater than 25 mm per hour. From May 21 to June 12, only 19 mm of rain were recorded. Rainfall, along with crop production activities and sampling times are shown in Figure 5.3.

Nutrient Inputs from Mulches and Ash

Residue weights on the surface of all plots prior to land clearing or burning averaged 8.5 tons ha^{-1} for Farm I and 4 tons ha^{-1} for Farm II. For the labranza cero treatment, these residues were left in place on the soil surface. The ash and partially

burned residues in the burned-field treatment contributed, at the beginning of the growing season, 10.4 kg N ha^{-1} and 3.4 P ha^{-1} for Farm I and 2.4 kg N ha^{-1} and 1.0 kg P ha^{-1} for Field II. Litter decomposition for the labranza cero treatment contributed, during the course of the growing season, 12 kg N ha^{-1} and 3.4 kg P ha^{-1} for Farm I and 4.9 kg N ha^{-1} and 1.2 kg P ha^{-1} for Farm II.

Soil Analyses

Erosion losses. Across treatments, erosion losses were not significantly different between farms (Figure 5.4 and Table 5.3). For both farms, soil losses from the cleared field and burned-field treatments were significantly greater than soil losses from the labranza cero treatment. Soil losses due to erosion from the labranza cero treatment of Farm II were greater than from the corresponding land preparation treatment of Farm I. During the 15 week growing season, soil erosion losses from Farm I ranged from 20 kg ha^{-1} for the labranza cero treatment to 687 kg ha^{-1} for the cleared-field treatment. Due to the drought, erosion losses were relatively low. No erosive rains fell from 9 DAP to 32 DAP.

Soil physical properties. Gravimetric moisture analyses taken in conjunction with midseason plant analyses indicated significantly lower moisture availability for the Farm I cleared-field treatment compared to the other land preparation treatments of Farm I (Table 5.3). Farm I exhibited lower soil penetrometer resistance at midseason and lower soil bulk density at harvest than did Farm II. Within farms, soil penetrometer resistance was lowest for the labranza cero treatment and highest for the cleared-field treatment (Figure 5.5a and Table 5.3). Farm II had a higher percentage of stable aggregates

greater than 2 mm in size at planting than did Farm I (Figure 5.5b and Table 5.3). No significant differences for soil bulk density or aggregate stability among land preparation treatments were found for either Farm I or Farm II.

Soil organic matter and pH . Farm II had higher soil organic matter and soil pH at planting and at harvest than did Farm I (Table 5.4). Across farms, the cleared-field treatment had significantly more soil organic matter than did the other land preparation treatments at planting. At harvest, no significant differences for soil organic matter were observed among land preparation treatments for either farm. The cleared-field treatment of Farm I exhibited a significantly lower pH than did the other land preparation treatments at planting. No significant differences for pH were observed among the land preparation of Farm II at planting. At harvest, across farms, the for pH the burned-field treatment was significantly higher than for the other land preparation treatments.

Phosphorus availability. Phosphorus availability was higher for Farm II than Farm I throughout the growing season. Changes in phosphorus availability throughout the growing season are summarized in Table 5.5. At two weeks after planting, the +P subplot of the Farm I labranza cero treatment had a distinctly higher level of phosphorus availability than did the -P subplot.

Nitrogen availability. Nitrogen mineralization, during all sampling periods, was significantly greater for Farm II (Table 5.6). No significant differences among land-preparation treatments or subplot treatments were observed for Farm II. For Farm I, a significant treatment by phosphorus effect was obtained. Both at 10 DAP and at harvest,

the +P subplot of the labranza cero treatment exhibited higher nitrogen mineralization than did the -P subplot.

For both farms, microbial biomass nitrogen was significantly lower for the labranza cero treatment than for the other land preparation treatments at five days before planting (Table 5.7). The labranza cero treatment of Farm I exhibited significantly higher microbial biomass than the cleared-field and burned-field treatments of this farm at 10 DAP and at 24 DAP. The cleared-field treatment of Farm II had significantly higher microbial biomass nitrogen than either of the other land preparation treatments of this farm at 10 DAP.

Mid-season Analyses

Above-ground plant biomass. Farm II had significantly greater plant biomass at midseason than Farm I (Table 5.8). For Farm I, plants from the cleared-field treatment had a significantly lower weight than plants from the burned-field and labranza cero treatments. Differences between +P and -P subplots were significant at 0.0004 for Farm I but were only significant at the 0.0865 level for Farm II.

Nodule numbers. Nodule numbers were significantly higher for Farm II than Farm I (Table 5.8). For Farm I, plants from the cleared-field treatment had significantly fewer nodules than plants from the burned-field and labranza cero treatments. No significant differences among land preparation treatments were observed for Farm II. For both farms, the +P subplots exhibited significantly more nodules than the -P subplots. Differences in nodule numbers at the rhizobia inoculation sub-subplot level

were significant only at the 0.1210 level for Farm I but were significant at the 0.0339 level for Farm II. Nodule numbers were low for all treatments due to the drought.

Phosphorus and nitrogen uptake. Farm II had significantly higher nitrogen and phosphorus uptake than Farm I (Table 5.8). No significant differences for nitrogen uptake were obtained at the land preparation treatment, phosphorus subplot, or rhizobia inoculation sub-subplot levels for Farm II. For Farm I, the labranza cero treatment exhibited higher nitrogen uptake than the other two land-preparation treatments .

Significant differences in P uptake were observed among land preparation methods for each farm. For Farm I, the labranza cero treatment had the highest P uptake, while for Farm II the burned-field treatment exhibited the highest P uptake. For both farms, the lowest P uptake was observed with the cleared-field treatment. No significant differences in P uptake were obtained at either the phosphorus subplot or the rhizobia inoculation sub-subplot levels for Farm II. For Farm I, P fertilization significantly increased phosphorus uptake for the cleared-field treatment.

Harvest Analyses

Weed incidence and labor inputs for weeding. All land preparation treatments for Farm II required significantly more time to weed than their corresponding treatments for Farm I (Figure 5.6a). For Farm II, no significant differences among land-preparation treatments were observed. The Farm I labranza cero treatment required significantly less time to weed compared to the two other land preparation treatments.

At harvest, Farm II exhibited significantly greater weed infestation compared to Farm I. For Farm II, no significant differences among land preparation treatments were

observed (Figure 5.6b). For Farm I, significant differences in weed infestation were observed among all three land preparation treatments. The labranza cero treatment had the lowest weed infestation whereas the cleared-field treatment had the highest weed infestation.

Web blight incidence. Despite an application of fungicide two weeks after planting, Farm II had a significantly higher incidence of web blight compared to Farm I (Table 5.9). Across farms, the labranza cero treatment exhibited the lowest incidence of web blight. The burned-field +P subplot of Farm I had a higher web blight incidence than did the corresponding -P subplot.

Yields. Across farms, Farm II produced significantly higher yields than Farm I (Table 5.9). For Farm II, the burned-field treatment produced significantly higher yields than the cleared-field treatment. Yields from the labranza cero treatment were intermediary to yields obtained from the other two land-preparation treatments. For Farm I, the burned-field and labranza cero treatments produced significantly higher yields than did the cleared-field treatment. Phosphorus fertilization resulted in significant yield increases for all land-preparation treatments of Farm I. Yields from the +P labranza cero and the +P burned-field subplot treatments were not significantly different for either farm.

The percent of diseased or damaged seeds was significantly higher for treatments from Farm II compared to Farm I. Consequently, when yields were adjusted to account for poor seed quality, average yield differences between Farm I and Farm II were no longer significant (Table 5.9). At the subplot level of analysis, the +P labranza cero and

the +P burned-field treatments of Farm I produced greater saleable yields than their counterparts for Farm II.

Discussion

Land Degradation

Both farms in this study had previously degraded soils including rocky outcroppings and incipient gully formation. Farm I, despite being located less than 500 meters from Farm II and having been in fallow for three years during the current cycle, had significantly lower soil fertility than Farm II. This was demonstrated, for example, by the lower soil organic matter content and P availability of soils on this farm. The soils of Farm I became red upon drying while the soils of Farm II were brownish. The clay contents of the two soils were similar, but Farm I had more silt while Farm II had more sand. An examination of the profiles of the two farms indicated that the current topsoil for Farm I was probably part of the original B horizon, whereas the soil profile of Farm II retained some of the original A horizon.

The inability of the three-year fallow to restore soil fertility is consistent with studies from India and Belize, which have demonstrated that fallows of at least ten years are required to produce observable increases in soil phosphorus levels (Ramakrishnan and Toky, 1981; Arnason et al., 1982). Intensive land-use had arrested successional processes for both farms included in the current study. This was indicated by their fallows being dominated by grasses. The deflection of successional processes for Farm I resulted in a low diversity of fallow growth vegetation, in low fallow biomass production, and

in retardation of phosphorus accumulation. Grasses are less effective in maintaining soil organic matter and nutrient levels, and in recycling mineralized nutrients, than are woody fallows (Aweto, 1981; Vitousek, 1984). The high lignin content of woody residues inhibits mineralization activities and enhances organic matter formation. Deep root systems of trees effectively recover leached nutrients.

Land degradation for Farm II was more apparent with regard to web blight and weed incidence than with regard to soil fertility. In order not to confound treatment and weeding effects, weeding and fungicide applications were intentionally limited to those required by the treatment with the lowest incidence of weed growth and web blight infestation. The thick mulch layer of the Farm I labranza cero treatment provided complete control of weeds and web blight. In contrast, the predominantly maize-stalk mulch of Farm II was insufficient to control the regrowth of thick-growing grasses. Weed infestation has frequently been mentioned as a limiting factor in the intensification of land-use in the tropics (Nye and Greenland, 1960; Wade and Sanchez, 1983; Peters and Neuenshwander, 1988).

The build-up of web blight inoculum under the continuous maize-bean rotation resulted in moderate to high levels of infestation by this disease in all land preparation treatments of Farm II. A fungicide was applied to this farm two weeks after planting to control an observed infestation. Infestation levels for this field probably would have been even more severe had rainfall been normal. The lack of rains during the vegetative stage of growth reduced the incidence of web blight to relatively low levels throughout the area.

Effect of Environmental Factors on Yields

Drought. A severe drought started at 8 DAP and continued until the beginning of the flowering stage of growth (see Figure 5.3). These dry conditions resulted in the soils of the cleared-field treatment of Farm I exhibiting a significantly lower moisture content than soils of either the labranza cero or burned-field treatment of this farm. The limited water availability for this treatment resulted in both low midseason plant biomass and low yields. Midseason plant biomass for the cleared-field treatment of Farm II was not noticeably affected by the drought. The difference in the effect of the drought on the two farms was probably due to the lower sand content of the soil for Farm I combined with the slightly more moist micro-environment of Farm II. Farm I was located on an exposed hillside whereas Farm II was located within a slight depression. Although rainfall at the two locations was similar, morning mists provided more moisture to the site of Farm II.

Phosphorus and nitrogen. Phosphorus fertilization resulted in significant increases in nodulation of bean roots for the labranza cero and cleared-field treatments of both farms. Phosphorus has been shown to influence bean nodulation and nitrogen fixation activity (Keyser and Munns, 1979). The increased nodulation levels associated with phosphorus fertilization were accompanied by significant differences in nitrogen uptake for the labranza cero treatment of Farm I. The ineffectiveness of nodulation to increase nitrogen uptake for the cleared-field treatment was probably due to the drought. Root observations, in conjunction with nodulation determinations, showed premature sloughing of nodules from roots of the cleared-field treatment.

Phosphorus additions resulted in increased midseason biomass and crop yields for all land-preparation treatments of Farm I, but not for Farm II. The increased availability of phosphorus for Farm I was reflected in the higher levels of phosphorus uptake from the +P subplots of the cleared-field treatment. Phosphorus availability and nitrogen mineralization were significantly increased by phosphorus fertilization for the Farm I labranza cero treatment. For subplots not receiving phosphorus fertilizer, mulching resulted in an immobilization of nitrogen and phosphorus during the first month after planting. The decreased availability of these nutrients during the vegetative phase of plant growth resulted in significantly lower midseason biomass and yields for the -P subplots.

Phosphorus contributions from ash inputs to the burned-field treatment averaged 6.7 kg P ha^{-1} for Farm I. As a result, yield differences between +P and -P subplots for this treatment were less significant than for the other two land-preparation treatments.

Nutrient Recycling and Nutrient Losses in the Soil System

Erosion. Erosion losses from the cleared-field and burned-field treatments were greater than from the labranza cero treatment of either farms. The greater mulch cover for Farm I resulted in reducing soil losses from the labranza cero treatment of this farm to only 25% of the erosion losses recorded for the labranza cero treatment of Farm II. Recent fallowing did appear to decrease the erodibility of the soil in Farm I. Soils from both farms had similar soil erodibility as measured by aggregate stability. The ineffectiveness of the fallow in decreasing soil erodibility may be due to the rapid decomposition of the grass fallow root system compared to a more woody root system.

Alternatively, the low nitrogen status of the soil may have depressed the growth of mycorrhizae responsible for aggregate formation in this fallow. Aziz and Habte (1989) showed that nitrogen deficiency in eroded soils depressed mycorrhizal activity of cowpeas.

Microbial biomass and nutrient availability for plant uptake. Analyses of microbial biomass provided an early indication of increased nitrogen availability for the labranza cero treatment. At planting, this treatment exhibited the lowest level of microbial biomass nitrogen. By 14 and 28 DAP this treatment had the highest microbial biomass nitrogen levels. The higher pool of labile nutrients for the labranza cero treatment of Farm I was reflected by the higher nitrogen and phosphorus uptake observed for this treatment compared to the other land preparation treatments. These results are consistent with previous studies associating no-tillage or mulch-based farming systems with higher levels of microbial biomass (Follett and Schimel, 1989; Hayes and Knight, 1989). Furthermore, the strong relationship obtained between mulching, nitrogen mineralization, phosphorus fertilization, and phosphorus availability confirms the importance of phosphorus in the organic fraction to soil fertility and crop yields in this area.

Estimate of Profitability of Bean Production

An estimate of profits, at the land preparation level, was determined based on the value, in colones, of saleable beans harvested (Table 5.10). From the value, the cost of fungicides and labor required for manual weeding and fungicide application was subtracted. Other input costs were not included in the equation, since they were assumed

to be approximately equal. Results from these calculations indicated that profits from the continuously cultivated farm, Farm II, were only 69%, 76%, and 77% of the profits obtained from the cleared-field, labranza cero, and burned-field treatments, respectively, of the fallowed farm, Farm I.

For both farms, net returns from the burned-field and labranza cero treatments are similar. Based on the lack of significant differences between +P and -P fertilizer treatments for the burned-field treatment of Farm I, net returns for this treatment may be increased by not applying fertilizers. Conversely, the subtraction of discount values for soil degradation and soil erosion from the cleared-field treatment would decrease long-term net returns for this treatment.

Conclusions

As nutrients are depleted from the agroecosystem, the ability of fallows to rejuvenate the physical and chemical qualities of a soil decreases. For highly degraded soils, grassy fallows or fallows of less than five to ten years (depending on the prior history of fallowing) are unable to restore soil fertility or decrease soil erodibility. However, by fallowing, leaving fallow residues on the soil surface, and applying nitrogen and phosphorus fertilizers, high yields can be obtained from even a degraded soil. The mulch cover in the labranza cero treatment of the fallowed farm not only decreased soil losses due to erosion but enhanced microbial activity, and decreased production costs by inhibiting weed regrowth and the spread of web blight. By applying molluscacides,

labranza cero was implemented without losses due to slugs. Weeds were controlled for this treatment with a single manual weeding, using less than 2 jornales of labor ha^{-1}.

Although similar yields were obtained for the continuously cultivated fields as for the fallowed field, the costs of production were higher, and the quality of the seeds harvested lower, for the continuously cultivated field. For this field, weeding activities required 19.2 and 27.0 jornales ha^{-1} for the labranza cero and burned-field treatments, respectively. Despite the lengthy weeding time, weed regrowth was heavy during the flowering stage of bean growth. As a result of the increased labor costs and seed damage for the continuously cultivated field, profits were reduced to approximately 75% of profits from the fallowed field.

The weight of the mulch layer for the labranza cero treatment of the fallowed field was decreased only 25% due to decomposition processes during the growing season. Assuming this rate of decomposition, continued use of labranza cero, and annual additions of residues from maize stalks and weed growth of 3 tons ha^{-1}, an effective mulch layer may be maintained for two to three years before fallowing is required to restore the mulch layer. Considering reductions in net returns of 25% from continuously cultivated fields compared to fallowed fields, the duration between fallows would need to be at least four years to be economically justified.

Based on results obtained from this set of experiments, the following recommendations for frijol espeque are proposed for use by tenant farmers.

1. Labranza cero practices should be implemented in conjunction with natural or accelerated fallows.

2. Complete fertilizers high in phosphorus (eg. 10-30-10 instead of 12-24-12; N-P-K) should be applied to enhance nutrient availability from chopped residues.

3. As long as fallowed land remains available, the most profitable, although not the most sustainable, option available to tenants is to use burned-field frijol espeque practices in conjunction with minimal or no fertilizer inputs.

For land-holders, additional experiments should be conducted to compare the effect of natural, accelerated herbaceous fallows, accelerated woody fallows, and alley cropping practices on microbial processes, erosion control, and control of weed growth and web blight infestations. These studies may be conducted for use with either frijol espeque or frijol tapado production.

Studies conducted in the Peruvian Amazon showed that Stylosanthes guianensis, Centrosema macrocarpum, and Pueraria phaseoloides were effective in controlling weed growth but were less effective than woody fallows in restoring soil fertility. Conversely, woody fallows were less effective in controlling weed growth but were more effective in restoring soil fertility (Szott et al., 1991). Future studies should examine accelerated fallows which include a combination of herbaceous and woody species.

12 mm = 1000 meters

0 1000 2000 3000 4000 5000

METERS

Figure 5.1: Location of farms included in the study in relationship to Pejibaye. (Source of Map: Instituto Geográfico Nacional, 1975).

Edge of the plastic erosion trough attached to the soil by staples

Sheet metal and horizontally cut PVC pipe serving as gutter to direct runoff to trough

Erosion plot showing sheet metal barrier at the head of the plot and trenches along the vertical edges

Figure 5.2: Erosion runoff plot design.

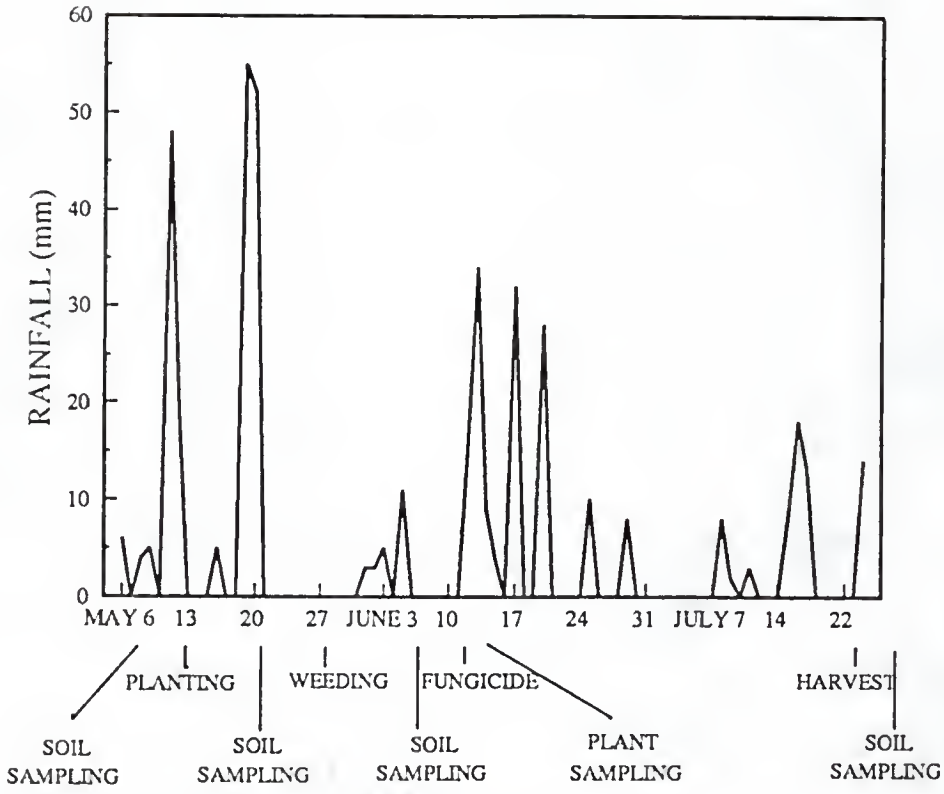


Figure 5.3: Rainfall, agricultural acitivities, and sampling times.

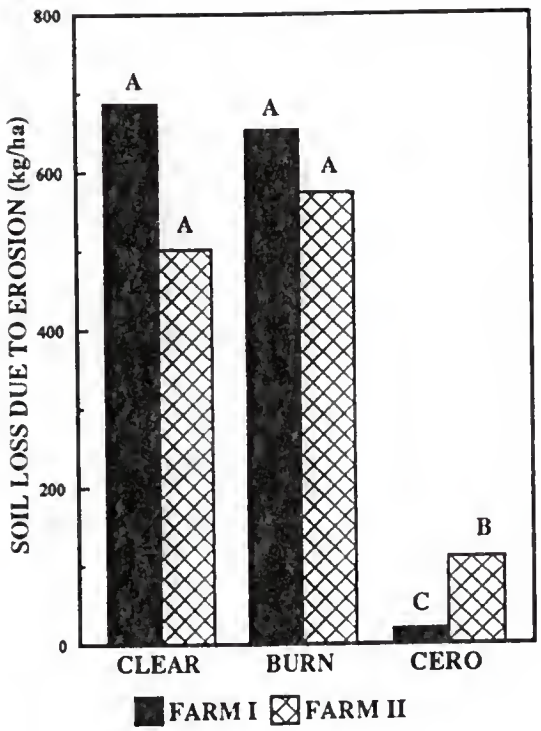


Figure 5.4: Cumulative soil losses due to erosion during the growing season.

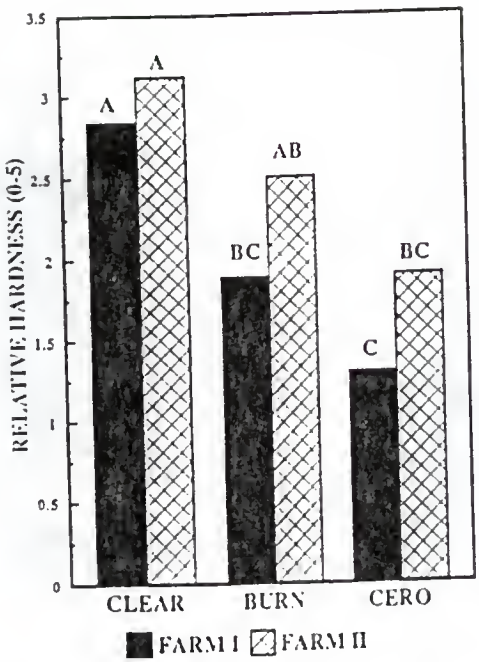


Figure 5.5a: Penetrometer resistance at midseason.

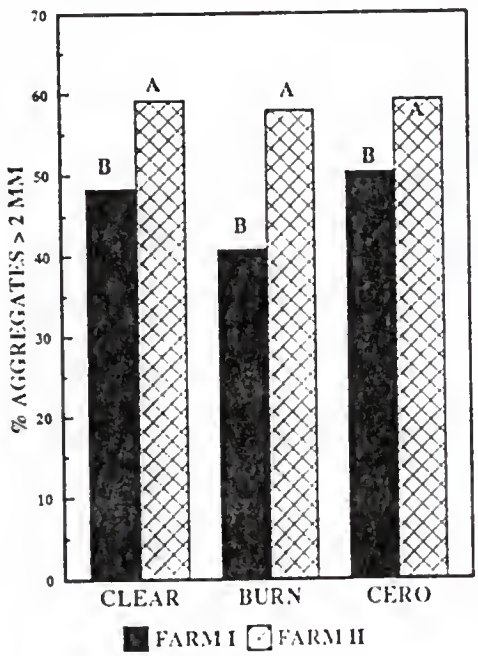


Figure 5.5b: Aggregate stability at planting based on the percent of water stable aggregates >2 mm.

Figure 5.5: Soil physical properties.

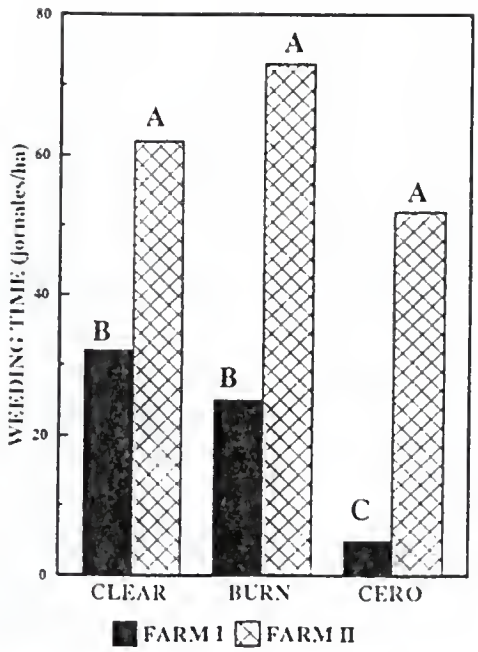


Figure 5.6a: Time required to weed treatments at two weeks after planting.

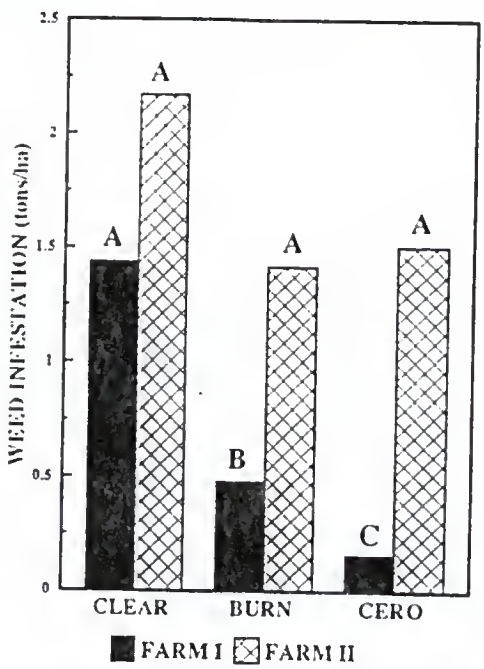


Figure 5.6b: Weed infestation at harvest.

Figure 5.6: Time required to weed treatments at two weeks after planting and weed infestation at harvest.

Table 5.1: Physical characteristics, prior land use, and predominant fallow species of experimental farms.

FARM	ASPECT	SLOPE (%)	PRIOR LAND USE	FALLOW SPECIES[a]
1	NW	68	3 years in grass fallow	jaragua, guarumo, tora, tuete, paira, churristate
2	NE	75	more than 8 years of continous bean-maize rotation	maize residues, tarquesa, zacate peludo, abrojo, moriseco

a. Scientific names for plant species are listed in Table 2.2

Table 5.2: Soil characteristics of experimental farms.

FARM	CLAY (%)	SILT (%)	SAND (%)	pH	OM (%)	P (ppm)[a]
1	27.2	25.2	47.3	6.2	4.2	5.2
2	30.0	34.4	35.6	6.2	5.0	18.8

a. Phosphorus determined using a modified Olsen solution.

Table 5.3: Soil physical characteristics.

TREATMENT	SOIL EROSION (kg ha^{-1}[a])	AGGREGATE STABILITY[b]	MOISTURE[c] (%)	PENETRO-METER[d]	BULK DENSITY[e] (g cm^3)
FARM I					
Clear	687±392	48.3	14.8	2.84	0.94±0.08
Burn	653±363	40.8	18.1	1.89	0.96±0.11
Cero	20±8	50.2	24.0	1.30	0.96±0.04
FARM II					
Clear	502±33	59.2	nd[f]	3.12	0.99±0.03
Burn	574±286	57.9	nd	2.51	1.01±0.02
Cero	111±7	59.2	nd	1.91	1.05±0.03

a. Soil erosion losses during the 15 week growing season.
b. Percentage of water stable aggregates greater than 2 mm. Determined at planting.
c. Determined at midseason.
d. Relative hardness on a scale of 0-5. Determined at midseason.
e. Determined at harvest.
f. Not determined.

F Values

SOURCE	EROSION	AGGREGATE STABILITY	MOISTURE	PENETRO-MENTER	BULK DENSITY
Farm	0.15	33.15	----	3.32	2.07
Land prep	14.72	1.02	147.0	8.18	1.57
Farm*Prep	0.74	0.54	----	0.15	0.53

Table 5.4: Soil organic matter and pH at planting and at harvest.

	PLANTING		HARVEST	
TREATMENT	ORGANIC MATTER (%)	pH	ORGANIC MATTER (%)	pH
FARM I				
Clear	4.44	6.0	4.10	5.8
Burn	4.19	6.2	3.30	5.8
Cero	3.97	6.2	4.26	5.9
FARM II				
Clear	4.90	6.3	4.83	5.9
Burn	4.53	6.1	5.04	6.1
Cero	4.32	6.2	4.70	5.9

F Values

	PLANTING		HARVEST	
SOURCE	ORGANIC MATTER	pH	ORGANIC MATTER	pH
Farm	4.08	0.29	24.51	3.87
Land prep	2.85	2.07	1.17	1.71
Farm*Prep	0.13	1.12	1.11	2.19

Table 5.5: Phosphorus availability throughout the growing season.

TREATMENT	SAMPLING PERIOD				
	20 DBP (ppm[a])	5 DBP (ppm)	10 DAP (ppm)	24 DAP (ppm)	HARVEST (ppm)
FARM I					
Clear +P	4.46± 2.32	3.59± 1.69	5.95± 1.23	4.99± 2.02	5.69± 1.14
Clear -P	4.00± 1.11	3.80± 1.24	4.82± 0.39	4.34± 1.03	4.28± 0.80
Burn +P	4.46± 2.40	6.15± 2.27	6.62± 2.02	5.85± 0.86	5.37± 0.97
Burn -P	6.36± 2.50	5.90± 2.84	7.69± 2.80	5.74± 0.66	4.88± 1.02
Cero +P	8.05± 8.84	2.97± 1.11	10.77± 8.51	6.18± 2.14	5.47± 1.74
Cero -P	3.84± 3.01	2.92± 0.41	5.79± 0.47	4.28± 0.90	4.01± 1.06
FARM II					
Clear +P	23.85± 14.15	19.90± 9.31	23.59± 7.43	14.58± 2.16	22.76± 8.81
Clear -P	18.72± 15.64	19.02± 11.07	24.35± 9.01	11.00± 4.11	16.69± 12.25
Burn +P	23.95± 6.88	20.15± 4.29	29.23± 7.54	15.94± 6.10	27.42± 8.68
Burn -P	21.64± 2.74	26.41± 10.72	22.97± 2.36	19.35± 5.00	19.73± 4.94
Cero +P	11.49± 1.95	16.69± 9.46	22.00± 6.80	14.85± 4.24	15.40± 6.08
Cero -P	13.44± 3.34	16.41± 8.35	17.13± 6.71	13.82± 5.51	12.14± 3.16

a. Extracted using a modified Olsen solution.

Table 5.5: continued

F Values

TREATMENT LEVEL	SAMPLING PERIOD 20 DBP	5 DAP	10 DAP	24 DAP	HARVEST
Farm	35.82	69.74	37.22	64.93	14.89
Land prep	1.06	1.08	0.66	1.89	10.03
Farm*Prep	1.59	0.18	1.58	0.76	8.62
Farm I					
Land prep	0.23	6.85	0.94	0.69	0.16
Phosphorus	0.51	0.00	0.99	2.11	3.67
Prep*P	1.90	0.06	1.10	0.75	0.39
Farm II					
Land prep	1.50	0.54	1.16	1.39	10.19
Phosphorus	0.21	0.38	2.37	0.04	3.68
Prep*P	0.27	0.38	0.92	1.04	0.19

Table 5.6: Nitrogen mineralization throughout the growing season.

TREATMENT	SAMPLING PERIOD		
	5 DBP-10 DAP (ppm NO_3-N)	10 DAP-25 DAP (ppm NO_3-N)	25 DAP-HARVEST (ppm NO_3-N)
FARM I			
Clear +P	3.10±2.52	5.57±1.41	12.60±5.81
Clear -P	4.13±1.36	4.97±1.12	13.07±3.55
Burn +P	2.17±2.71	4.57±4.76	6.00±1.71
Burn -P	2.63±2.47	7.93±5.78	9.70±1.47
Cero +P	3.17±2.90	4.00±4.79	15.43±4.31
Cero -P	0.87±1.50	4.33±5.86	9.03±0.30
FARM II			
Clear +P	27.00±4.70	14.37±11.40	23.80±2.61
Clear -P	20.93±20.75	9.57±5.66	27.87±6.53
Burn +P	27.70±3.79	12.63±0.51	27.93±4.06
Burn -P	18.63±11.46	8.03±4.96	30.13±9.21
Cero +P	13.70±2.74	9.83±1.04	30.57±4.90
Cero -P	18.70±6.34	14.23±4.28	32.10±2.43

Table 5.6: continued

F Values

SAMPLING PERIOD

TREATMENT LEVEL	5 DBP-10 DAP	10 DAP-24 DAP	24 -75 DAP
Farm	18.18	8.88	99.20
Land prep	3.05	0.05	1.95
Farm*Prep	1.70	0.65	2.94
Farm I			
Land prep	1.36	0.37	1.84
Phosphorus	0.11	1.14	0.55
Prep*P	1.65	1.53	8.78
Farm II			
Land prep	2.44	0.33	3.60
Phosphorus	0.65	0.23	0.86
Prep*P	1.04	0.76	0.07

Table 5.7: Microbial biomass nitrogen throughout the growing season.

	SAMPLING PERIOD			
MICROBIAL BIOMASS	5 DBP ppm N[a]	10 DAP ppm N	25 DAP ppm N	HARVEST ppm N
FARM I				
Clear +P	123.39± 10.75	81.36± 11.45	113.54± 5.46	118.07± 5.28
Clear -P	118.21± 7.01	77.19± 6.27	104.38± 11.15	101.64± 15.53
Burn +P	135.02± 15.96	81.18± 12.77	111.21± 1.49	118.60± 4.87
Burn -P	120.81± 18.50	80.88± 31.65	107.43± 12.29	121.43± 3.93
Cero +P	107.63± 6.66	110.90± 20.16	122.58± 17.53	108.22± 6.90
Cero -P	102.72± 3.72	101.21± 18.16	123.51± 7.62	115.67± 15.98
FARM II				
Clear +P	84.74± 19.36	111.86± 6.26	106.12± 12.70	nd[b]
Clear -P	91.17± 9.08	118.98± 30.50	103.22± 12.78	nd
Burn +P	86.99± 41.06	93.97± 15.32	106.62± 12.42	nd
Burn -P	80.97± 29.05	90.93± 15.59	115.62± 8.39	nd
Cero +P	66.84± 45.27	91.03± 20.53	114.69± 4.70	nd
Cero -P	70.95± 30.62	101.92± 15.53	112.19± 4.30	nd

a. Ninhydrin reactive nitrogen
b. Not determined

Table 5.7: continued

F Values

SAMPLING PERIOD

TREATMENT LEVEL	5 DBP	10 DAP	24 DAP	HARVEST
Farm	26.64	1.80	0.50	---
Land prep	1.05	4.08	6.26	---
Farm*Prep	0.08	9.46	1.48	---
Farm I				
Land prep	6.84	8.18	6.01	1.99
Phosphorus	3.51	0.44	1.52	0.22
Prep*P	0.51	0.15	0.81	2.87
Farm II				
Land prep	0.25	5.39	1.83	---
Phosphorus	0.06	0.27	0.07	---
Prep*P	0.38	0.19	0.77	---

Table 5.8: Midseason plant analyses.

TREATMENT	PLANT BIOMASS (g plant^{-1})	NODULES (no. plant^{-1})	N IN PLANT (%)	P IN PLANT (%)
FARM I				
Clear +P	1.17±0.43	8.3±4.2	3.41±0.51	0.25±0.04
Clear -P	0.68±0.14	3.1±0.9	4.14±0.14	0.20±0.01
Burn +P	2.23±0.71	12.7±6.7	3.54±0.31	0.29±0.04
Burn -P	1.59±0.68	9.7±3.4	3.98±0.53	0.30±0.02
Cero +P	2.20±0.41	18.2±9.9	3.94±0.63	0.35±0.05
Cero -P	1.40±0.20	9.7±5.9	4.29±0.69	0.34±0.01
FARM II				
Clear +P	2.51±0.56	21.1±5.9	4.87±0.44	0.39±0.03
Clear -P	2.40±0.70	13.6±6.7	5.15±0.46	0.38±0.06
Burn +P	2.52±0.49	19.8±7.9	4.91±0.59	0.46±0.02
Burn -P	2.33±0.42	17.6±11.2	4.88±0.50	0.44±0.03
Cero +P	2.79±0.43	22.9±5.8	4.90±0.45	0.41±0.04
Cero -P	2.51±0.33	15.0±3.5	4.99±0.33	0.42±0.04

Table 5.8: continued

F Values

LEVEL	PLANT BIOMASS	NODULES	N IN PLANT	P IN PLANT
Farm	8.77	10.39	14.52	31.18
Land prep	4.47	1.47	0.57	31.08
Farm*Prep	3.51	0.66	0.68	13.96
Farm I				
Land prep	5.09	1.49	0.82	30.45
Phosphorus	52.23	17.58	21.40	0.68
Prep*P	0.96	1.46	1.65	2.03
Rhizobia	0.10	3.96	0.00	0.12
Farm II				
Land prep	0.76	0.13	0.10	10.31
Phosphorus	4.19	12.37	1.61	1.63
Prep*P	0.27	1.21	1.02	0.97
Rhizobia	3.63	0.54	1.66	0.95

Table 5.9: Harvest analyses.

	WEB BLIGHT (% incidence)	YIELDS (kg ha^{-1})	SALEABLE YIELDS (kg ha^{-1})
FARM I			
Clear +P	1.3±2.1	1283.3±86.2	1234.2±93.9
Clear -P	0.0±0.0	729.2±144.3	686.3±144.4
Burn +P	5.0±7.6	2007.0±295.8	1956.3±315.9
Burn -P	2.0±3.2	1822.0±215.4	1758.8±214.1
Cero +P	0.0±0.0	1950.0±269.2	1873.3±276.3
Cero -P	0.0±0.0	1482.7±259.1	1403.8±272.8
FARM II			
Clear +P	10.7±9.4	1592.6±127.9	1274.2±313.0
Clear -P	11.0±11.2	1527.8±373.7	1298.7±406.3
Burn +P	14.0±17.3	1931.5±439.6	1610.5±663.5
Burn -P	7.0±9.4	2005.3±549.4	1778.5±689.1
Cero +P	4.7±4.3	1770.3±219.5	1575.0±288.7
Cero -P	5.2±5.1	1851.7±211.1	1631.8±174.3

Table 5.9: continued

F Values

TREATMENT LEVEL	WEB BLIGHT	YIELDS	SALEABLE YIELDS
Farm	1.89	2.69	0.04
Land prep	1.83	15.25	13.23
Farm*Prep	0.58	2.54	1.83
Farm I			
Land prep	1.93	51.36	53.23
Phosphorus	1.33	129.10	63.48
Prep*P	0.48	9.91	4.36
Rhizobia	2.41	4.11	2.83
Farm II			
Land prep	1.08	1.63	1.48
Phosphorus	0.78	0.26	2.21
Prep*P	1.13	0.65	0.60
Rhizobia	0.57	0.54	0.97

Table 5.10: Estimate of net returns from beans as affected by yields and weeding expenses.

TREATMENT	LABOR COST[ab]	VALUE OF BEAN YIELD[c]	NET RETURNS[d]	% DIF.[e]
FARM I				
Clear	4095	61700	57605	----
Burn	3220	97800	94580	----
Cero	630	93650	93020	----
FARM II				
Clear	21595	64300	39980	69%
Burn	9450	84700	72525	77%
Cero	6720	80150	70705	76%

a. All values are in colones ($1 US = 107 colones, 1-1-91) and based on one hectare.
b. Based on the number of jornales required to weed one hectare. Each jornal is valued at 350 colones.
c. Based on yields obtained from +P subplots. Beans are valued at 50 colones per kilogram.
d. Bean value - (labor cost for weeding + cost of fungicide application + cost of fungicide).
e. percent of net returns obtained in Farm II compared to the respective land preparation treatment in Farm I.

CHAPTER 6
THE SUSTAINABILITY OF BEAN FARMING ON STEEP LANDS: EVALUATION OF THE CONSEQUENCES OF TECHNOLOGY INTRODUCTION ON THE AGROECOSYSTEM AND ON THE FARMING COMMUNITY

Introduction

The introduction of agronomic recommendations does not occur within a vacuum. Neither are agricultural recommendations introduced into a homogeneous society or a uniform environment. Interactions among technology adoption, the environment, and the farming community determine the impact of introduced agricultural technologies on agroecosystem sustainability.

The introduction of frijol espeque into Pejibaye de Pérez Zeledón occurred in response to increasing land-use intensity for maize and bean production. Government programs providing farm loans and markets accompanied the introduction of frijol espeque in order to encourage resource-poor farmers to adopt this input-based farming practice. Simultaneously, the construction of an asphalt road enhanced the articulation of this previously isolated farming community with the urban sector. As the farming community became integrated into the market economy, farmers decreased their use of the primarily subsistence-oriented frijol tapado, in favor of the market-oriented frijol espeque.

Although frijol espeque exhibited high productivity when initially introduced, this productivity has not been sustainable. Several factors, both within and outside the sphere

of the technology introduction program, diminished the productivity of frijol espeque. When frijol espeque was initially introduced, extension personnel recommended the use of cleared-field methods to expedite crop-maintenance activities and to control slug infestations. Cleared-field methods exhibited high productivity on experiment stations having flat to slightly rolling terrain. These technologies, however, proved to be inappropriate for the steeply-sloping, highly erodible lands traditionally used for bean production in Pejibaye.

The research conducted in conjunction with this study confirmed the association between continuous cultivation of beans on steeply-sloping land and increased land degradation, decreased bean yields, and decreased profitability. It also confirmed the relationship between high labor and agrochemical input based farming systems and increased inequality. As small-scale farmers increase land-use intensity, they increase their economic risks for bean production. As these farmers incur debts by farming degraded land, they are encouraged, if not forced, to sell their land to large-scale cattle ranchers.

Simultaneous with the introduction of frijol espeque, farm-loan programs for cattle production encouraged land-owning farmers to place former bean-production land into pasture. This decreased the availability of land for tenant bean farmers as well as the availability of labor opportunities for day laborers. In a circular fashion, as on-farm labor opportunities decreased and access to off-farm labor opportunities increased, the availability of laborers for bean production decreased. This further encouraged cattle ranchers to decrease the amount of land used for bean production. As a result, the

poorest sector of the farming community was further impoverished, and out-migration of the sons and daughters of small-scale and tenant farmers was precipitated. Consequently, due to interactions between bean and cattle production programs, the environment, and the farming community, a program designed to increase the productivity of bean growing was transformed into a cycle of degradation (Figure 6.1).

Trade-offs Between Productivity and Sustainability in Bean Production

In the experiments conducted, the high productivity of cleared-field frijol espeque was associated with low sustainability. Cleared-field frijol espeque produced both significantly higher yields and significantly greater soil losses due to erosion compared to frijol tapado. Soil losses of up to eight tons per hectare were reported for frijol espeque during a 12 week growing period. Mulches associated with frijol tapado effectively controlled erosion but they also decreased bean emergence, resulting in low yields. Low bean emergence was associated with fallows of two years or less. The thick grasses of short-term fallows, especially when wet, produced a heavy and, at times, impenetrable cover. When beans were dibble-stick planted rather than broadcast, grass mulches no longer prevented bean emergence. Consequently, labranza cero produced significantly higher yields than frijol tapado and yields that were either only slightly lower or not significantly different from cleared-field frijol espeque. Labranza cero, produced using a short-fallow mulch, significantly reduced soil erosion, weed growth, and web blight infestation compared to cleared fields. The retention of residues also significantly enhanced phosphorus availability and nitrogen mineralization of a phosphorus deficient soil.

Labranza cero grown in rotation with a short fallow exhibited both the short-term productivity of cleared-field frijol espeque and the sustainability of frijol tapado. Farmer adoption of this practice, however, depends on trade-offs between the availability of labor, land, and cash. Since labor is the time limiting factor at planting, farmers prefer the convenience of planting in cleared fields. Most farmers interviewed said that they would have to reduce the area planted by 25% to 50% if they were to adopt labranza cero. This may be a misperception due to lack of personal experience. Farmers who have adopted labranza cero noted that the time required to plant labranza cero decreased as they became accustomed to planting through a mulch cover. Unfortunately, accurate estimates of differences in planting time between treatments could not be estimated from these experiments due to need to plant experimental plots precisely.

To adopt labranza cero, farmers also would need to decrease the intensity of land-use. A field must be placed in fallow every three years in order to maintain a mulch cover sufficient to control weed and web blight infestations. Since infestations of weeds and web blight have become yield-limiting, farmers may be willing to trade-off increased land-use intensity for increased sustainability, yield stability, and per-season productivity.

Impact of Technology Introduction on Agroecosystem Sustainability

Impact of bean growing practices on the four factors of social value.

Important information regarding the impact of technology introduction on the environment and on society was obtained by using all four factors of social value to compare the traditional and the introduced technologies of bean growing. In the research conducted, frijol espeque exhibited high per-season productivity, high yield response to improvements in

the environment, low sustainability of production using constant levels of inputs, and low equitability (Table 6.1). Conversely, frijol tapado had low productivity, but exhibited high stability across environments and high sustainability. Labranza cero, using occasionally fallowed land, had high per-season productivity, high stability, and high sustainability. Land availability and land-tenancy status affected the equitability of both frijol tapado and labranza cero.

Impact of government programs on the profitability and sustainability of bean farming. Changes in the implementation of government bean production programs also affected the profitability and sustainability of bean farming. During the one-and-one-half year duration of the research reported here, several factors occurred which could cause problems in the sustainability of program implementation. MAG personnel, recognizing the high rates of erosion associated with clear-field frijol espeque production, encouraged farmers to adopt labranza cero as a soil conservation measure. They promoted this recommendation without information regarding its impact under local farming conditions. Research conducted in conjunction with this study showed that these practices, as promoted, were ineffective in achieving their intended goal.

In 1990, the National Bank (BNCR) only made input loans for bean production available to farmers planting two hectares or more of beans. This regulation excluded all tenant farmers and over one-half of the farmer landowners from access to loans. In 1991, the CNP developed an ambitious extension program to encourage farmers to increase their bean production. Farmers joined this program based on promises of interest-free loans for inputs and food, as well as vouchers to pay for the cost of

transporting beans from their farm to the buying station. In reality, this program only provided input loans.

Consequently, small-scale farmers became distrustful of extension programs. They perceived these programs as not addressing their needs. During interviews, many farmers said "lack of assistance from the government and from extension agents" was one of their most serious agricultural problems. This mistrust of extension programs will impede the implementation of future programs.

The Development and Evaluation of the Sustainability of Agricultural Recommendations

Factors Affecting Sustainability

Agroecosystem sustainability encompasses the environment, the agricultural system, and the farming community. Environmental sustainability is based on community diversity, balances between pests and predators, resource conservation and recycling, and a maintenance of linkages between communities of organisms within and outside the agroecosystem. Agricultural and economic sustainability of the agroecosystem are dependent on environmental sustainability. Agricultural sustainability encompasses the balance between environmental sustainability and productivity, while economic sustainability encompasses the balance between productivity and equity.

The current emphasis on developing and implementing sustainable agricultural development programs is in response to programs perceived as enhancing social inequities. These programs were criticized as being production-oriented and researcher-managed rather than equity-oriented and farmer-managed (Chambers and Jiggins, 1987a).

To achieve sustainability, the priorities, structures, and management of development programs need to be reoriented. In contrast to traditional top-down, researcher-managed development approaches, sustainable agroecosystem development provides mechanisms for people in the farming community to take control of their own development (Korton, 1983). For the development and dissemination of agricultural technologies to be sustainable, a technical analyses of agricultural methodologies is insufficient. The political agenda to provide farmers with the ability to implement recommendations must also be promoted (Altieri, 1989). The priorities of sustainable development do not emphasize growth and productivity, but instead emphasize the importance of equity (de Janvry and Garcia, 1988; Korton, 1990). Moreover, sustainable development processes approach development from the viewpoint of systems analysis rather than analyzing discrete agronomic, environmental, and socioeconomic components (Conway, 1991). In summary, sustainable agroecosystem development is community oriented, equity based, politically dynamic, and holistic.

Developing Agricultural Recommendations

The formation of agricultural recommendations, based on sustainable agricultural development, involves farmers and an assessment of their indigenous technologies. The development of technologies should address all sectors of the farming community. In Pejibaye, tenants accounted for one-third of the bean farmers. The introduction of recommendations requiring long-term control over the land excludes tenants from the development process. Equity of program development involves simultaneously addressing the political constraints to land reform while testing agricultural

recommendations that tenant farmers can implement. For resource-poor farmers, both monetary and labor resources are scarce. Therefore, the introduction of recommendations requiring increased monetary or agrochemical inputs should not be promoted until infrastructural constraints, availability of farm loans, and risks associated with technology adoption have been considered. Recommendations requiring increased labor inputs involve trade-offs with the needs and opportunities for labor in other on- or off-farm activities.

Analyzing Agricultural Recommendations

On-farm experiments are conducted to analyze interactions between agricultural technologies and farm conditions. They are also conducted to compare introduced technologies and current farmer practices (Shaner et al., 1982). Although trials are conducted on several farms, analysis procedures usually used consider the "farmer practice" as a single treatment. Analysis procedures that combine all farmer practices into a single treatment are insensitive to assessing differences in farmer practices or identifying potentially useful indigenous technologies.

Research conducted by Ellitta et al. (1991), Russell (1991), and in conjunction with this study indicated that farmer practices are not uniform and should not be considered as a single treatment. Instead, experiments should be designed to include not only comparisons between farmers' practices and introduced technologies, but also comparisons among the farmers' treatments. This can be accomplished by analyzing both the variability among the farmers' practices studies and the variability withing each farmer's practices. Suitable experimental designs would include separating the farmer-

managed "farmer practice" treatment into replicate blocks. Agronomic data from each block would be analyzed separately. The replication of data in the farmers' practices is conducted to permit more precise comparisons of the environmental and management factors affecting the productivity and sustainability of the farmers' practices. Results from an integrated agronomic and socioeconomic analysis of farmers' practices can be used also to identify farmer constraints and opportunities, as well as indigenous technical knowledge. To compare the farmers' practices against introduced technologies data from the replicate blocks would be averaged.

The modified stability analysis procedure provides information on the response of agricultural technologies to differing environmental conditions. This statistical method is based on regression analyses rather than on procedures which average treatment responses, as in ANOVA. The regression analyses used in MSA provide an estimate of treatment-by-environment interactions. The "modified" stability analysis procedure recommended for on-farm trials differs from stability analyses used by plant breeders in two regards (Hildebrand, 1990; Russell, 1991). First, treatments with a stable response to environment are not rejected in favor of treatments with a high environmental response. Second, treatment-by-environment interactions are exploited to determine which treatment recommendations are appropriate for the recommendation domains identified.

Russell (1991) argued that the environmental responses obtained in MSA are highly dependent on the environments included in the study. For this reason, recommendation domains identified using MSA are "predictive" rather than definite. He recommended using MSA as an adjunct to, rather than a replacement for, more standard

analytical methods. Stroup et al. (1991) concurred, noting that MSA should be considered as a preliminary, and not a final, tool.

Based on the studies reported here, the integration of MSA and ANOVA statistical methods in a two-step process is recommended. During the initial growing season, a broad assessment of the variability within the environment should be given priority over determinations of within-field variability. Accordingly, treatments should not replicated on each farm but, instead, installed on as many farms as possible; the farms chosen to represent a wide range of environmental conditions and farmer practices. A detailed analysis of the "farmers' practices" also should conducted in conjunction with this study. Based on assessments of treatment-by-environment responses and indigenous farmer knowledge, treatment selection and modification by recommendation domain can be determined preliminarily. During the second growing season, the modified treatments then can be tested, as replicated trials, on selected farms representative of environments within each recommendation domain. This two-step procedure provides both broad-based treatment-by-environment, and precise within-environment, analyses. The combination of information allows researchers, in coordination with farmers, to modify technologies and to provide appropriate recommendations for other, similar environments.

Analyses of Productivity and Degradation

Despite criticisms of production-oriented agriculture, yield data continues to dominate most on-farm experiments. In this study, the treatment producing the highest yields also produced the greatest soil degradation. Also, increased input use permitted the production of acceptable yields while masking soil degradation. These conclusions

indicate that analyses limited to measurements of productivity may result in the promotion of recommendations which decrease agroecosystem sustainability. The analysis of soil and input-use data in conjunction with yield data effectively separates processes of land degradation from the factors of yield production.

Soil data collected in conjunction with on-farm experiments provides information regarding limiting nutrients, physical constraints, and disruptions of microbial processes. Phosphorus is often cited as the major limiting nutrient in tropical soils (Arnason et al., 1982; Singh, 1990; Szott et al., 1991). Due to the low availability of mineral forms of phosphorus in highly weathered soils, phosphorus from organic sources forms an important component of the labile phosphorus pool. Thus, analyses conducted to assess crop and environmental response to mulching and green manures should include determinations of the availability of phosphorus from organic sources. Appropriate determinations include assessments of phosphorus in microbial biomass, incubation tests, or a combination of soil nitrogen mineralization and phosphorus availability analyses, as used in the experiments reported here.

The precision of the scientific analyses should be consistent with the precision of the statistical analyses. The modified stability analysis procedure is conducted as an initial, predictive form of analysis. Accordingly, scientific analyses conducted in conjunction with MSA should include simplified techniques, qualitative analyses, or indicator data providing initial, predictive information. As replication is abandoned in favor of greater breadth of environments in MSA, precise analyses of single factors should be abandoned in favor of analyses providing estimates for a variety of factors. In the experiments reported here, analyses based on indicators or estimates provided

initial information regarding changes occurring in the agroecosystem. Microbial biomass and aggregate stability analyses provided predictive information on labile nutrient pools and soil erodibility, respectively. Simple erosion runoff plots, costing less than $10 each for materials and installation, provided important qualitative, if not precisely quantitative, information on soil losses. Partial budget analyses of labor inputs provided an estimate of decreasing profitability of bean production.

During the second phase of on-farm experimentation fewer treatments and locations are used. In these studies, more precise and detailed information may be collected to verify the predictive information obtained during the initial growing season.

Reprioritizing Agroecosystem Values: Placing Equity First

The sustainability of agricultural development programs for resource-poor farmers depends on the involvement of farmers in their own development. Analytical techniques, such as runoff plots, which can be understood by the farmers should be included in experimental set-ups. Additionally, low-cost analysis methodologies should be used whenever possible so as to not allocate funds away from programs more directly assisting the farmers. Additional, recommendations should promote greater equity rather than result in greater displacement and disempowerment of the poorest sector of the population.

Currently, agricultural development programs are constrained administratively by the necessity to propose specific recommendations prior to the onset of program development (van Sant and Crawford, 1985; van der Heijden, 1987, Hellinger et al., 1988). They are constrained scientifically by researchers placing their own professional

advancement ahead of the needs of farmers (Chambers and Jiggins, 1987a; Chambers, 1989). They are also constrained socioeconomically by the obligation to operate in compliance with bureaucratic structures and governments which are often non-democratic (Korton, 1987; Nyoni, 1987).

Several workers in international agricultural development have argued that sustainable development depends not only on simply reorienting technologies to the needs of resource-poor farmers, but also reorienting the priorities and objectives of development itself (Conway, 1985; Redclift, 1987; Altieri, 1989, Korton, 1989). They maintain that increasing productivity without equity and empowerment of the poor cannot produce sustainable development.

To effect change in the priorities of agricultural development programs, mechanisms are needed to assess the impact of development on the entire agroecosystem. Yields provide a measure of productivity. Assessment of sustainability or equity, however, requires an integrated analysis of environmental, agronomic, and economic criteria. Evaluations of these factors should be conducted primarily by project participants, since they are best able to perceive how the project fits within the context of their lives (Bryant and White, 1984). In this process, researchers and other project personnel do not direct the evaluation process but serve instead as catalysts, assisting farmers in establishing their own evaluation criteria for comparing treatments (Drabrek, 1987).

Sustainable agricultural development, therefore, requires a sensitive integration of scientific data and community participation. The research reported here provides a blueprint for obtaining the scientific data necessary for analyzing the impacts of technology introduction on the balances between sustainability, equity, and productivity.

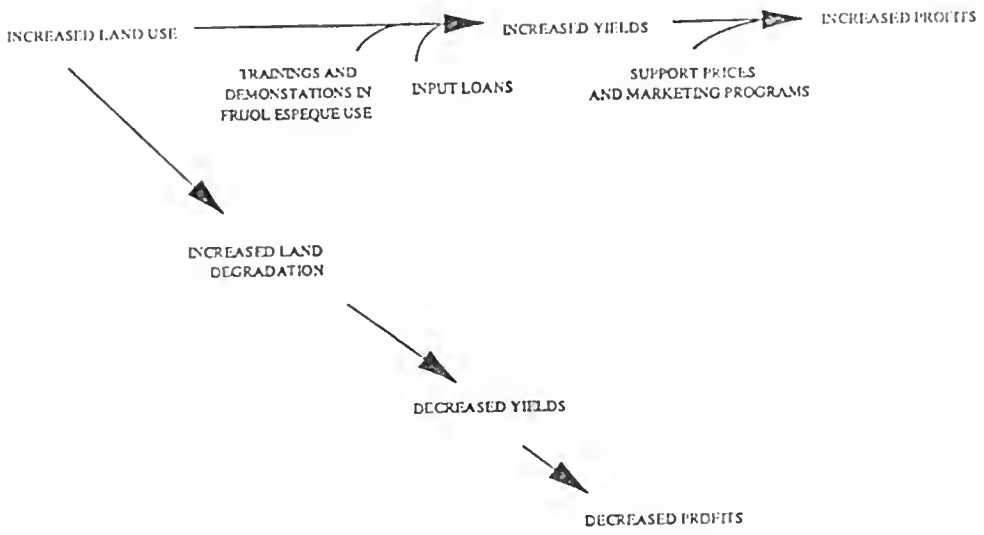


Figure 6.1a: Idealized effect of agricultural technology transfer.

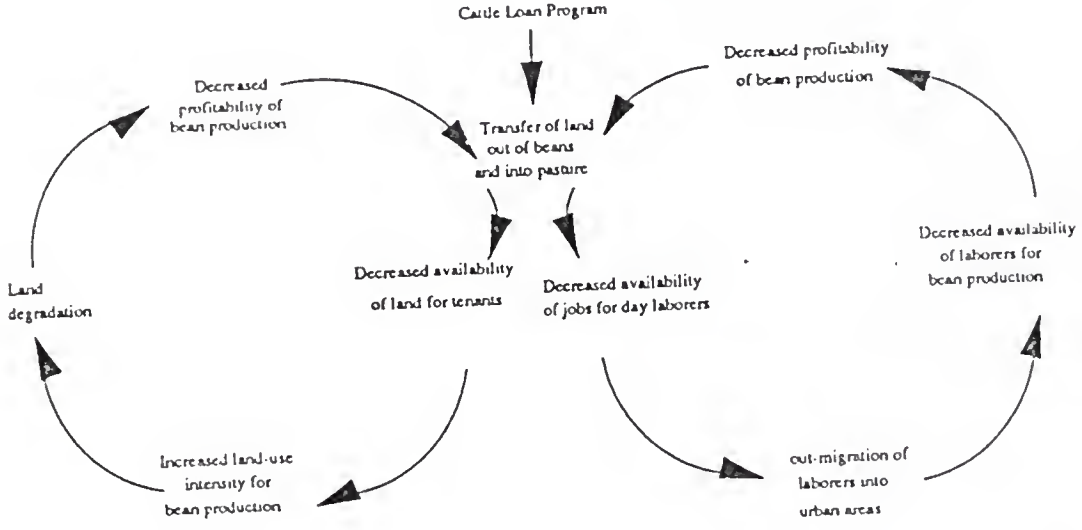

Cattle Loan Program
Decreased profitability of bean production
Decreased profitability of bean production
Transfer of land out of beans and into pasture
Decreased availability of land for tenants
Decreased availability of jobs for day laborers
Decreased availability of laborers for bean production
Land degradation
Increased land-use intensity for bean production
out-migration of laborers into urban areas

Figure 6.1b: Impact of cattle loan programs on the sustainability of bean production on steep lands in Costa Rica.

Figure 6.1: Contradicting effects of government programs on the sustainability of bean production.

Table 6.1: Agroecosystem factors of social value for frijol tapado, labranza cero, and frijol espeque, as practiced on steep lands.

FRIJOL TAPADO	LABRANZA CERO	FRIJOL ESPEQUE
PROFITABILITY		
low yields	high yields	high yields
low land-use intensity	medium to high land-use intensity	high land-use intensity
STABILITY		
diversity of income sources	low labor inputs	high labor inputs limits off-farm employment
plant diversity and stabilization of pest and predator populations during fallows	mulch layer protects against spread of web blight and weed regrowth	build-up of pest and weed infestations
		input use needed for stable yields
SUSTAINABILITY		
mulch layer protects soil against erosion and compaction due to raindrop impact	inclusion of fallows provides sufficient mulch to control erosion and compaction due to raindrop impact	clear-field planting encourages soil erosion, soil compaction, and soil drying
soil moisture conserved and nutrient recycling enhanced by mulches and fallows	soil moisture, P availability, and organic matter conserved by mulches and fallows	loss of organic matter and nutrients during land clearing and burning
EQUITABILITY		
high return on investment	intermediate return on investment	low return on investment
low risk	intermediate risk	high risk
requires ownership of sufficient land to fallow or rental of fallowed land	requires ownership of sufficient to use occasional fallows or access to fallowed land for rental	intensified land-use increases short-term profits
does not require cash outlays	requires cash outlays for fertilizers and herbicides.	requires cash outlays for fertilizers, herbicides, and fungicides as well as high labor inputs for weeding

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APPENDIX A
INTRODUCTORY SURVEY

Nombre del Agricultor: _____
Fecha de la Encuesta_____
Lugar_____

1. Cuál es el area de la finca? Manzanas_____

2. Es la finca donde trabaja propia? Sí___ No_____
   Si la tierra es propia:
   a. Cuántos años ha trabajado usted en este finca? _____
   b. Ha el área aumentando _____ o disminuido_____ desde el tiempo que empezó a trabajar en esta finca?
   c. Tiene alguna tierra que es alquilada por arrendatarios Sí _____ No _____

   Si la tierra es alquilada por la personna que contesta:
   d. Trabaja en esta finca:
      (1) a medias _____ a tercio _____
      (2) Cuantos años ha trabajado en la misma tierra? _____

3. 4. Tapó usted frijoles el año pasado? Sí____ No____
   a. Va a tapar frijoles este año? Sí ____ No____
   b. Sembró usted frijol espeque en el año pasado? Sí ____ No____
   c. Va a sembrar frijol espeque este año? Sí____ No____

5. Qué más tiene en su finca ademas de frijol?
   maiz_____ café_____ árboles frutales_____
   árboles de plantacion_____ montaña_____
   ganado_____ tomate_____ otro_____

6. 7. Dónde vivó antes de vivir aquí?_____
   a. Cuál era su trabajo antes de vivir aquí?_____
   b. Le gusta trabajar en la finca? Sí ____ No ____
   c. Por qué le gusta o no le gusta? _____
   _____

8. Por favor conteste sí o no a las siguientas preguntas:
   a. El trabajo de la finca es muy cansador? Sí___ No____
   b. Los gastos de la finca siguen aumentando mientras las ganancias siguen disminuyendo? Sí ____ No _____
   c. La vida de finca no es muy segura? Sí ___ No ___
   d. La vida de finca es mejor que la vida en las ciudades porque en las fincas hay comida siempre? Sí ____ No ____
   e. Le gustaria que sus hijos fueron agricultores? Sí ____ No_____

9. Sí tapa el frijol:
   a. Por qué?_____
   b. Dónde lo tapó el año pasado? _____
   c. Cuál es la topografia del lugar que utilizó para tapar frijol?
   Ondulado ____ Quebrado ____ Muy Quebrado ____
   d. Cuántas manzanas ____ tenia el lugar donde tapó el frijol?
   e. Tapa siempre en esta tierra? Sí ___ No ___
   f. Cuántos años tiene el breñón donde tapó el frijol? _____
   g. Cuántas cosechas va a sembrar en esta tierra antes de dejarla descansar otro vez? _____

10. Qué variedad de semilla de frijol usó? _____
   a. Por que usó esta variedad de semilla? _____
   b. Cuál era la procedencia de las semillas?
      propia_____ CNP_____ vecinos_____
      otra _____
   c. Son las semillas utilizadas seleccionadas? Sí _____ No _____
   d. Qué problemas tuvó el año pasado con frijol tapado?
   barbosas_____ vaquites_____ jabotos_____
   chasperia _____ parajos_____
   sequía_____ lluvia fuerte_____
   tierra consada _____ erosión _____
   semillas nacidas _____ malezas _____
   otro _____
   e. Usó algunos insumos como abono, pesticidas, o semillas mejoradas cuando tapó frijoles? Sí ____ No ____
      Si la respuesta es afirmativa:
      (1) Cuáles? _____
      (2) Por qué? _____
   Si la repuesta es negativa:
      (3) Por qué? _____

f. Usó alguna mano de obra fuera de la famila para tapar frijoles?
Sí _____ No_____
Si la respuesta es afirmativa:
(1) Para tapar? _____ jornales
(2) Para cosechar? _____ jornales
(3) Para otras actividades? _____ jornales
Qué actividades? _____

g. Qué metodo usó para desgranar el frijol?
manual_____ chapuling _____

h. Qué fueron los rendimientos del frijol tapado el año pasado? _____

11. Si siembra frijol espeque:
a. Por qué?_____
b. Dónde va a sembrarlo este inverniz? _____
c. Cuál es el tipo de topografia del lugar donde va a sembrar frijol espeque?
Plano ____ Ondulado ____
Quebrado ____ Muy Quebrado ____ Mixto ____
d. Cuántas manzanas ____ tiene el lugar donde va a sembrar frijol espeque?
e. Cuándo va a sembrar frijol espeque? Inverniz _____ Veranero _____
f. Qué va a sembrar durante la otra cosecha?
Maiz _____ Otro _____
g. Esta tierra, lo usa siempre para frijol espeque?
Sí ___ No ____
(1) Cuándo fue la ultima vez que dejó a descansar la tierra donde va a sembrar frijol espeque? _____
(2) Cuándo va a dejar a descansar esta tierra otra vez?
_____
(3) Para cuántos años va a dejarla en descansar?
_____

h. Cómo prepara la tierra para sembrar frijol espeque?
Chapea_____ Quema con fuego _____
Herbicidas_____ Bueyes_____ Maquineria_____
(1) Si no quema con fuego:
Deja rostrojo encima de la tierra
Sí ____ No ____
(a) Si la respuesta es afirmativa: Por qué?
Para evitar erosión? _____
Para controlar las malezas? _____
Para aumentar la fertilidad de los suelos? _____
Otro _____

(2) Si quema con fuego, Por qué?
para facilitar labores?_____
es barato?_____
para controlar malezas? _____
para controlar babosas?_____
para controlar plagas o enfermedades?_____
por costumbre? _____
otro _____

i. Qué variedad de semilla de frijol usa? _____
(1) Por qué usa esta variedad de semilla? _____
_____

1) Cuál era la procedencia de las semillas?
propia _____ CNP_____ vecinos_____
otra _____
(2) Son las semillas utilizadas selecionadas?
Sí _____ No _____

i. Aplica el abono al frijol espeque? Sí _____ No_____
Si la respuesta es afirmativa:
(1) A la hora de la siembra:
tipo _____
cantidad _____
método de aplicacion _____
(2) Después de la siembra:
cuándo_____ tipo _____
candidad_____
método de aplicación _____
(3) Si no usa el abono, por qué?
tierra nueva _____ falta de recursos _____
otro _____

j. Qué problemas tuvó el año pasado con el frijol espeque?
babosas_____ vaquites_____ jabotos_____
chaspería _____ parajos_____
sequía _____ lluvias fuerte _____
tierra consada _____ erosión _____
malezas _____
falta dinero para comprar los insumos o pagar la mano del obra
_____
falta disponibilidad de mano del obra _____
mercadeo_____ otro_____

k. Usó usted algunos insomos como herbicidas, fumigación o caracolicida el año pasado en los lotes de frijol espeque?
_____

l. Usó mano del obra fuera de la famila para ayudarlo hacer algunos trabajos del frijol espeque? Sí _____ No _____

Si la respuesta es afirmativa:

(1) Para sembrar: _____ jornales

(2) Para cosechar:_____ jornales

(3) Para otras actividades: _____ jornales

Cuáles trabajos? _____

m. Cuál fueron los rendimientos del frijol espeque el año pasado?

_____ quintales

12. Piensa usted que algunos montes que crecen en los breñones son buenos?

Sí ____ No ____

Si la respuesta es afirmativa:

a. Cuáles?_____

b. Por qué piensa usted que estos montes son buenos?

No dan mucho competencia al frijol_____

Pueden aumentar la fertilidad del suelo _____

Pueden evitar los problemas de la erosión _____

Pueden cortarlas con facilidad _____

Otros_____

c. Cuáles montes son malos _____

d. Por qué piensa usted que estes montes son malos?

Crecen rápido_____ Dan mucho molestia_____

Otro_____

13. Por favor conteste sí o no a las siguientas preguntas:

a. Para cultivar el frijol gasta más pero rienda menos ahora que anteriormente? Sí____ No____

b. Es muy importante limpiar los suelos de cualquier rastrojo o basura de las plantas para que no tenga problemas con las babosas? Sí____ No____

c. La quema no da ninguna molestia al suelo? Sí____ No____

d. El frijol espeque riendo más que el frijol tapado? Sí____ No____

e. El frijol espeque gasta desmasiado mano del obra? Sí____ No____

f. El frijol tapado es un método que no es muy arriesgado? Sí____ No____

g. Es muy importante que tenga algun lugar en la finca para cultivar el frijol? Sí____ No____

h. Puede seguir sembrando frijol espeque en esta finca por muchos años más? Sí____ No____

i. Puede sembrar frijol espeque en el mismo lote que usa para frijol tapado? Sí____ No____

j. Es más importante usar la tierra tanta como posible que dejarla a ratos descansar? Sí____ No____

14. Si la tierra esta cansada:
    a. Qué podria hacer?
    La deja descansar _____ Aplica mas abono _____
    Para de quemar la tierra con fuego _____
    Deja la basura en la tierra _____
    Aplica más pesticidas _____
    La usa para pasto _____
    La usa para cafetal _____
    La usa para plantaciones_____
    Otro _____
    Nada _____

APPENDIX B
FRIJOL ESPEQUE ECONOMIC SURVEY

Entrevistador _____
Fecha de la encuesta _____
Nombre del Agricultor: _____
Lugar de la finca: _____

1.a. Es usted dueño _____ arrendatario _____ de la finca donde trabaja.
b. Si es dueño de la finca, cuántas manzanas _____ tiene su finca en total?
c. Si es arrendatario, cuántas manzanas _____ esta trabajando?
d. Cuántas manzanas _____ tenía para frijol inverniz?

2.a. Usa usted solamente mano de obra propia para hacer los trabajos del frijolar?
Sí _____ No _____
b. Paga usted peones para hacer algunos trabajos del frijolar?
Sí _____ No _____
Trabaja con propia mano de obra y peones? _____
Trabaja con peones solamente? _____

3.a. Cuántos jornales gastó usted en total para limpiar o preparar la tierra para frijol espeque?
chapear _____ montonar el rostrojo _____
quemar con fuego _____
b. Cuántos jornales pagó usted para la preparación de la tierra? _____
c. Cuántos jornales de mano de obra familiar gastó para echar los herbicidas?
_____
d. Cuántos peones pagó usted para echar herbicidas? _____
e. Cuántos jornales de mano de obra familiar gastó para sembrar el frijol?
_____
f. Cuántos peones pagó usted para sembrar el frijol? _____
g. Cuántos jornales de mano de obra familiar gastó para abonar el frijol?
_____
h. Cuántos peones pagó para abonar el frijol? _____
i. Cuántos jornales de mano de obra familiar gastó para echar fumigación e insecticidas? _____

j. Cuántos peones pagó usted para echar fumigación e insecticidas?
_____

k. Cuántos jornales de mano de obra familiar gastó para desyerbar a mano?
_____

l. Cuántos peones pagó usted para desyerbar a mano? _____

m. Cuántos jornales gastó de mano de obra familiar para arrancar, amontanar, y tapar el frijol? _____

n. Cuántos peones pagó usted para cosechar el frijol? _____

4.a. Usó herbicidas en su frijolar? Sí _____ No _____
Si la respuesta es sí:

b. Cuál tipo de herbicida usó en su frijolar? _____

c. Cuántos kilos o galones de <u>cada</u> herbicida usó? _____
_____

5.a. Qué variedades de semillas sembró? _____
_____

b. Cuántos kilos _____ o cajuelas _____ de semilla usó?

c. Cuántos semillas sembró de golpe? _____

d. Las semillas que usó, fue guardadas? _____
desde el consejo (CNP)? _____

6.a. Abonó el frijol? Sí _____ No _____
Si la respuesta es si:

b. Qué tipo de abono usó?
el primer abonar _____ segunda abonar _____

c. Cuántos kilos o quintales de abono usó?
el primer abonar _____ segunda abonar _____

d. Si la repuesta es no: Por qué? _____

7.a. Usó usted algo fumigación? Sí_____ No _____
Si la respuesta es si:

b. Qué tipo de fumigación usó? _____

c. Cuántos kilos o litros de <u>cada</u> tipo de fumigación usó?
_____

8.a. Usó used algun insecticida? Sí _____ No _____
Si la respuesta es si:

b. Qué tipo de insecticida usó? _____

c. Cuántos kilos o litros de <u>cada</u> insecticida usó?
_____

d. Usa usted fumigación o insecticidas como prevención? Sí _____ No _____
o solamente cuando ve algo daño en el frijol? _____

9.a. Qué método usó para aporrear el frijol?
manual _____ macánico (trillador) _____
b. Cuántos colones tuvo que pagar por cada quintal de frijol desgranando con trillador? _____
c. Si desgranó el frijol manualmente, cuántos jornales de mano de obra familiar gastó para desgranar el frijol? _____
d. Si desgranó el frijol manualmente, cuántos peones pagó usted para desgranar el frijol? _____

10.a. Dónde compró usted los insomos de frijolar? _____
b. Cómo trajo los insomos al campo? _____
c. Cuántas horas gastó usted cada vez que tenía de comprar y traer algunos insumos al campo? _____
d. Cuántos veces por cosecha tuvo que ir al centro para comprar los insomos?
_____

11.a. Pidió usted algun prestamo de dinero para el trabajo del campo?
Sí _____ No _____
b. Si la respuesta es afirmativa, pidió usted prestamos de dinero del banco? _____ Al comprador? _____

12. Qué trabajo dentro del frijolar hizo cada miembro de la familia?
Esposo _____
Esposa _____
Hijos (Cuántos) _____
Hijas (Cuántas) _____
Otros (Cuántas personas) _____

13.a. Cuántos quintales de frijol recogió? _____
b. Dónde vendió usted el frijol? _____
c. Cuál fue el precio que recibió usted por su frijol?
por kilo _____ por todo _____

14.a. Nececitó transportar los recojidas de su frijolar hasta algún lugar para venderlo?
Sí _____ No _____
b. Si la respuesta es afirmativa: Cómo transportó el frijol?
_____
c. Cuántos horas gastó usted o cuánto tuvo que pagar para transportar el frijol?
_____

APPENDIX C
FRIJOL TAPADO SURVEY

Entrevistador _____
Fecha de la encuesta _____
Nombre del agricultor: _____
Lugar de la finca: _____

1.a. Tapa usted el frijol? Sí _____ No _____
b. Siembra usted el frijol? Sí _____ No _____
c. Tapa usted el frijol en tierra propria _____ o en tierra alquilada _____?

2.a. Si tapa usted en tierra alquilada, es este trabajo a medias _____ a tercio _____?
b. Cuántas manzanas _____ tapó usted este año?
c. Si trabajó usted en tierra alquilada, tiene usted tierra propia? Sí _____ No _____
d. Si la respuesta es afirnativa: cuántas manzanas _____ tiene y para qué usa usted esta tierra? _____

3.a. Si trabaja usted en tierra propia, cuántas manzanas _____ tiene la finca?
b. Cuántos manzanas de su finca usó usted el año pasado para:
frijol tapado _____ frijol sembrado _____
maíz _____ breñones _____ café _____
ganado _____ montaña _____ otras cosas _____

4.a. Siempre tapa usted el frijol cada año? _____ de vez en cuándo solamente? _____
b. Cuál es el topografía del lugar donde tapó frijoles?
Ondulado ____ Quebrado _____ Muy Quebrado _____
c. Tapa usted frijol en la misma tierra cada año? _____ o busca breñones diferentes cada año? _____
d. Qué tipo de tierra le gusta usar para tapar frijoles?
tierra que tiene: breñones de un año _____ breñones de más de un año _____ menos platanilla _____ menos helecho _____ breñones con jaragua _____ breñones con matas gruesas _____
otra _____

5.a Cuántos años tuvó el breñon donde tapó frijoles el año pasado?

_____

b. El breñon donde tapó frijol el año pasado, estaba totalmente en descanso antes de cortarlo? _____ lo usó durante el tiempo de descanso para pasto _____ para sacar leña _____ para maíz _____ para café _____ o para otras cosas _____

c. Después de cosechar el frijol tapado, qué hizo usted con la tierra donde tapó frijoles?
la dejó descansar _____ sembró maíz inverniz _____ sembró frijol inverniz _____ sembró café _____ echó ganado _____ usó para otras cosas _____

d. Si usó la tierra donde ha tapado frijoles para sembrar maíz o frijoles inverniz, como cuántas cosechas de frijoles y maíz va a sembrar en esta tierra antes de dejarla en descanso otra vez? _____

e. Si tapó frijoles año por año, siempre tapa frijoles como asi?
Sí _____ No _____
o a veces deja la tierra descansar por 2 ó 3 años? _____.

6.a. Si tapa frijol año por año, por qué no usa usted un breñon más grueso?

_____

b. Si tapa frijol año por año, qué tipo de montes tienen los breñones?

_____

7.a. Comó puede saber usted que tiene que dejar la tierra en descanso otra vez?
los frijoles no rinden nada _____ los frijoles tienen muchos enfermedades _____ hay muchas plagas _____ es difícil de controlar las malezas _____ tiene que usar más abono _____ otra _____

_____

b. Si deja la tierra descansar, por cuántos años la deja descansar?

_____

8.a. Qué variedades de semillas del frijol usó para frijol tapado?

_____

b. Por qué usó esta variedad de semilla? _____

_____

c. Las semillas que usa para tapar frijol son semillas guardadas del año pasado _____ o ha sido compradas de los vecinos _____ o del consejo (CNP) _____

d. Si usó semillas guardada del año pasado, seleccionó usted los frijoles que usó?
Sí _____ No _____

9.a. Cuántos kilos o cajuelas de semillas de frijol tapó por manzana?
_____

b. Usó usted algunas insumos (abono, herbicidas, caracolicida, o fumigación) en sus trabajos de frijol tapado? Sí _____ No _____

c. Si la respuesta es afirmativa: cuáles insomos usó?
_____

d. Si la respuesta es negativa: por qué no? _____

e. Ha probado usted de usar algunas insomos en sus trabajos de frijol tapado? Sí _____ No _____

f. Si la respuesta es afirmativa: qué puede decir de las resultados, digamos, piensa usted que vale la pena usarlos? Sí _____ No _____

10.a. Qué problemas tuvo el año pasado con la cultivación del frijol tapado?
babosas _____ la quema (chasparía) _____ lluvia fuerte _____ tierra cansada _____ erosión_____
malezas _____ otra _____

b. Qué hizo usted para evitar o disminuar las problemas en los lotes de frijol tapado?
tiró caracolida _____ tiró muchos semillas de frijol _____
echó abono _____ usó solemente tierra que tiene varios años de descanso _____ nada _____ otra _____
_____

11.a. Para hacer los trabajos de frijol tapado, usó usted solamente mano de obra familiar? Sí _____ No _____

b. Si pagó usted algunos peones para hacer estos trabajos: mano de obra familiar y peones _____ con manos cambiadas _____
con peones solamente _____

c. Cuántos jornales gastó usted para tapar frijoles?
trabajo familiar _____ peones pagados _____

d. Cuántos jornales gastó usted para arrancar el frijol tapado?
trabajo familiar _____ peones pagados _____

12. Qué trabajo dentro del frijolar hizo cad miembro de la famila?
Esposo _____
Esposa _____
Hijos (cuántos) _____
Hijas (cuántas) _____
Otras personas (cuántos) _____

13. Cuáles de los siguientes otros gastos tuvo usted para la producción de frijol tapado y cuánto pagó usted por cada gasto? Caracolicida _____
abono _____ cuchillo _____ lima _____
sacos _____ plástico para tapar _____ transporte _____
otra _____

14.a. Cuáles fueron los rendimientos de frijol tapado el año pasado? _____
quintales por _____ manzanas

b. Para qué usó los rendimientos del frijol tapado?
para tener frijol para gasto _____
para tener semilla para regar frijol el año proximo _____
para tener semilla para sembrar en inverniz _____
para vender _____

c. Dónde vendió usted sus frijoles?
a comerciantes _____ a CNP _____
otro _____

15.a. Qué otros trabajos hizó usted mientras creció el frijol tapado?
cosechó café _____ trabajó en el beneficio ____ podó café _____
sembró maíz _____ cuidó ganado _____ chapeó pastos _____
trabajó como peon en otras fincas _____
otro _____

b. Qué le da más ganancias, los trabajos de frijol tapado _____ o algunos de los otros trabajos que hizo usted? _____

c. Para pagar los gastos de la casa y la finca, qué puede decir de estos otros trabajos que hizo mientras creció los frijoles?
Son muy importante _____ son más o menos importantes _____
ayudan algo _____

d. Si cosechó café durante el tiempo que creció el frijol, trabajó usted en su propia finca? _____ otras fincas de este lugar _____
fincas de otros lugares _____

e. Cuántos dias trabajó usted el año pasado en su propia finca cosechando café?
_____
en las otras fincas? _____

f. Si trabajó usted cosechando café en las otras fincas, más o menos cuánto dinero ganó usted por este trabajo? _____

g. Si trabajó usted cosechando café en su propia finca, cuántas fornegas de café obtuvo? _____

h. Trabajaron tambien algunos de los familiares? Sí ____ No _____

i. Si la respuesta es afirmativa: cuáles de las familiares trabajaron cosechando café y por más o menos cuántos dias _____

16.a. Ha probado usted de sembrar el frijol en veranero en lugar de taparlo?
Sí _____ No _____
b. Si la respuesta es negativa: por qué no quiere sembrar el frijol en lugar de taparlo? _____
c. Si la respuesta es afirmativa: qué puede decir usted de las resultados de estos trabajos? _____
d. Si siembra usted el frijol veranero, como prepara usted la tierra para sembrar el frijol?
quema parejo _____ con montes encima de la tierra _____ con herbicidas _____ con pala _____
otra _____
e. Si sembró usted frijol veranero el año pasado, qué problemas tuvo?
_____
f. Si sembró usted frijol veranero el año pasado, cuáles fueron los rendimientos?
_____

17.a. Piensa usted seguir tapando frijol por muchos años más?
Sí _____ No _____
b. Si pensa usted seguir tapando frijol por muchos años más, por qué?
_____
c. Si pensa usted dejar el trabajo de tapar frijol por qué?
_____
d. Es difícil de consiguir tierra para tapar frijol?
Sí _____ No _____

18. Obtiene usted otras productos desde el lugar de frijol tapado fuera de frijoles?
leña _____ madera _____ estacas para cercas _____ comida o pasto para los animales _____ medicinas _____ otra cosas _____
_____

19.a. Algunas personas dicen que uno puede ganar mucho dinero en poco tiempo con el trabajo del frijol mientras otras personas dicen que el frijol no es rentable hoy. Qué piensa usted, es el trabajo de la agricultura rentable o no?
es rentable _____ no es rentable _____
b. Si piensa usted que el trabajo de la agricultura no es rentable hoy, tiene ganas de dejar el trabajo de agricultura o de sembrar/tapar frijoles y maíz sólo para el gasto?
Dejar agricultura _____ sembrar sólo para el gasto _____
seguir como siempre _____ otra _____
_____

c. Si piensa usted que los trabajos de agricultura son menos rentables hoy, por qué piensa usted que este trabajo es menos rentable hoy que anteriormente?
los insumos son caros _____ los precios de frijol son bajos _____
muchas plagas _____ la tierra está cansada _____ muchas malas
hierbas _____ otra _____

d. Si piensa usted que el trabajo de agricultura no es rentable hoy, qué piensa usted que podría hacer para hacerlo más rentable? _____
_____

e. Si tiene ganas de dejar el trabajo de agricultura, qué le gustaria hacer en lugar de este?
trabajar como peón _____ trabajar solamente con ganado _____
trabajar solamente con café _____ dejar el campo _____
otra _____

20. Qué considera usted son los problemas más graves que enfrenta usted como agricultor?
falta de recursos _____ falta de tierra _____ falta de
tiempo _____ falta de mano de obra _____ plagas _____ malas
hierbas _____ problemas de tiempo (lluvias fuertes o verano
fuerte) _____ tierra cansada _____ menos apoyo del
gobierno _____ dificultad de pedir prestamos de dinero para el trabajo de
campo _____ los precios por los productos _____
mercadeo _____ transporte _____
otra _____

21. Si tuviera suficiente tierra y dinero qué cambios le gustaría hacer en sus trabajos de campo?
sembrar café _____ tener ganado _____
hacer reforestación _____ dejar la tierra descansar más _____
trabajar con más técnica _____ otra _____

APPENDIX D
DATA FOR EXPERIMENTS DESCRIBED IN CHAPTER 4

Farm descriptions are provided, by number, in Chapter 4. Treatments: BARE=bare-field frijol espeque, CERO=labranza cero, GLIR=G. sepium mulched frijol espeque, TAP=frijol tapado, ROWS=cleared-field frijol espeque with windrows.

Soil analyses, at planting.

Soil organic matter, 0-15 cm, at planting (%).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	4.2	4.9	4.5	4.2	4.3
2	5.6	5.6	7.3	6.4	4.8
3	4.7	6.8	6.1	4.9	5.2
4	4.2	5.8	6.4	5.4	5.6
5	6.7	7.2	5.5	7.3	7.1
6	8.5	5.1	6.8	6.0	5.3
7	4.7	6.4	5.9	6.6	6.7
8	6.4	6.3	5.8	5.4	7.4
9	5.9	5.4	5.1	4.0	5.1

Soil phosphorus, 0-15 cm, at planting (ppm).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	3.8	7.8	5.2	13.5	8.9
2	55.8	54.7	154.0	123.0	80.0
3	20.0	113.0	41.7	33.4	107.0
4	10.9	4.1	4.4	3.8	3.6
5	107.0	91.0	68.0	125.0	130.0
6	23.6	7.3	2.8	9.2	2.2
7	11.5	32.0	73.0	56.0	53.0
8	3.5	7.4	9.7	4.6	4.6
9	14.6	41.8	18.3	40.3	14.1

Soil potassium, 0-15 cm, at planting (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	1.11	1.56	1.08	1.76	1.35
2	1.80	2.00	1.50	2.79	1.51
3	0.95	1.39	1.44	0.91	1.49
4	1.12	1.33	1.00	1.03	1.27
5	1.70	2.05	1.02	3.35	2.04
6	1.84	1.18	1.55	1.65	1.30
7	1.11	1.23	1.60	2.23	2.28
8	1.63	2.09	0.94	2.60	3.07
9	1.68	1.81	1.34	1.45	1.46

Soil calcium, 0-15 cm, at planting (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	28.8	25.2	30.5	24.8	29.7
2	25.4	29.2	33.6	28.0	33.9
3	33.9	29.3	26.4	28.2	25.3
4	26.8	15.1	22.1	21.4	21.3
5	35.6	32.3	46.2	32.3	31.9
6	34.5	32.0	27.8	23.4	28.2
7	30.9	33.1	34.5	31.8	32.6
8	26.0	21.7	26.6	27.9	25.1
9	26.1	32.8	29.8	33.7	32.2

Soil magnesium, 0-15 cm, at planting (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	6.91	4.50	6.11	6.05	6.47
2	4.01	4.30	5.02	3.35	4.75
3	5.41	2.93	3.16	4.08	2.76
4	4.96	4.40	4.28	3.41	3.31
5	3.34	3.72	3.01	4.08	3.72
6	4.86	4.40	4.82	4.90	5.28
7	5.88	5.91	6.19	5.99	6.71
8	5.73	8.75	6.57	7.46	7.14
9	4.20	4.17	4.28	4.33	4.18

Total soil cations, 0-15 cm, at planting (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	42.4	35.0	41.8	37.4	40.2
2	38.8	39.0	42.0	39.8	40.0
3	44.2	39.2	36.8	36.6	36.2
4	35.0	32.6	34.2	32.0	30.4
5	40.4	40.8	39.4	41.0	40.2
6	44.4	41.0	39.0	42.0	41.0
7	39.2	42.0	42.0	42.4	42.2
8	38.8	42.0	38.2	42.4	43.2
9	36.4	41.4	37.6	42.0	39.6

Soil organic matter 15-30 cm, at planting (%).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	2.9	3.7	3.7	4.0	4.1
2	4.1	4.1	4.6	5.4	4.3
3	3.5	4.6	4.2	3.9	4.2
4	4.2	4.4	3.5	4.5	5.0
5	4.4	5.6	4.1	5.4	4.9
6	4.7	4.8	5.3	4.5	4.3
7	4.2	3.9	3.0	4.2	4.0
8	3.9	4.7	3.7	4.4	5.6
9	5.0	3.8	5.0	3.7	4.6

Soil phosphorus, 15-30 cm, at planting (ppm).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	3.6	3.3	9.0	3.7	4.3
2	23.3	22.4	45.4	73.0	44.0
3	10.5	29.7	15.1	32.6	54.8
4	8.9	3.0	4.3	2.5	1.8
5	64.0	67.0	46.7	73.0	61.0
6	4.2	14.0	3.4	3.1	1.4
7	10.1	12.6	21.9	22.3	20.6
8	1.5	8.1	9.5	5.3	2.7
9	10.1	13.0	8.8	8.9	6.5

Soil potassium 15-30 cm, at planting (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	1.15	1.18	0.95	0.86	1.02
2	1.18	1.54	1.06	1.94	1.12
3	0.74	1.02	1.19	0.80	1.08
4	1.14	0.99	0.59	0.62	1.21
5	1.23	1.75	1.26	2.22	1.68
6	1.24	1.33	1.36	0.95	1.06
7	0.91	1.33	1.21	1.40	1.55
8	0.89	1.58	0.58	1.45	1.71
9	1.39	1.47	1.04	1.07	1.19

Soil calcium 15-30 cm, at planting (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	27.6	22.9	31.1	30.6	27.7
2	32.4	26.7	24.4	34.2	31.5
3	36.5	30.5	21.8	21.2	27.7
4	29.9	16.3	21.6	10.7	19.6
5	44.7	32.3	31.6	31.1	30.5
6	32.9	35.2	25.7	30.6	27.2
7	27.7	36.4	29.3	35.0	32.9
8	23.9	23.5	27.0	28.8	22.4
9	27.4	31.6	29.0	28.9	31.0

Soil magnesium 15-30 cm, at planting (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	6.01	4.35	7.12	5.16	6.53
2	4.38	3.47	4.49	3.41	3.76
3	5.44	2.61	2.70	3.84	2.84
4	5.10	3.78	3.86	3.26	3.15
5	2.88	3.28	2.88	3.62	3.20
6	4.98	4.11	4.51	3.84	5.21
7	5.66	5.34	5.88	5.31	6.07
8	5.40	8.98	6.61	6.88	6.38
9	4.38	4.00	4.20	4.09	4.00

Total soil cations 15-30 cm, at planting (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	40.0	32.0	40.5	38.0	41.0
2	38.0	36.4	38.6	38.4	38.8
3	42.6	36.4	34.4	36.2	34.6
4	36.0	32.2	32.0	31.6	31.4
5	39.6	41.4	38.2	40.2	41.0
6	41.8	44.2	36.8	39.6	40.2
7	39.4	43.8	38.4	41.4	39.4
8	36.0	41.4	38.0	40.2	40.3
9	37.6	41.0	38.2	40.6	38.4

Soil analyses, at harvest.

Soil organic matter, 0-15 cm, at harvest (%).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	5.7	7.8	5.4	7.0	5.5
2	6.4	5.4	5.9	8.1	5.7
3	4.3	8.0	6.6	5.4	5.4
4	7.7	5.8	5.9	7.0	7.2
5	5.8	6.3	7.0	7.9	6.8
6	8.3	7.9	9.5	7.1	7.1
7	6.4	8.3	4.4	4.5	6.3
8	6.4	9.0	7.8	6.7	8.6
9	6.4	6.9	7.5	6.0	6.2

Soil phosphorus, 0-15 cm, at harvest (ppm).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	15.0	17.0	5.7	22.0	8.0
2	72.0	50.5	52.6	126.0	96.0
3	21.0	131.0	80.0	44.5	45.6
4	29.2	1.2	9.3	6.7	3.6
5	46.4	53.0	104.0	90.0	62.0
6	8.3	10.0	4.0	11.0	2.0
7	22.8	44.0	76.0	75.0	58.0
8	5.8	3.8	2.6	3.5	4.2
9	24.0	80.0	32.2	29.2	13.5

Soil potassium, 0-15 cm, at harvest (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	1.10	2.11	1.37	1.83	1.55
2	1.49	1.80	0.82	1.69	1.79
3	1.16	1.90	1.18	1.06	0.88
4	1.33	1.50	0.84	1.45	2.01
5	1.24	1.87	1.71	2.30	2.32
6	0.99	1.19	1.48	1.85	1.70
7	0.85	1.47	1.93	1.96	1.74
8	1.52	2.17	1.06	2.00	2.99
9	1.61	2.09	1.85	1.69	2.02

Soil calcium, 0-15 cm, at harvest (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	.	28.4	31.8	25.7	30.5
2	.	25.0	.	.	34.4
3	35.6	36.0	.	28.3	28.0
4	28.9	23.6	13.9	22.1	24.4
5	35.4	32.1	25.1	35.0	15.3
6	.	31.9	20.9	23.3	20.1
7	.	36.6	23.2	39.0	32.8
8	27.3	26.0	25.5	30.7	17.5
9	27.4	37.0	30.1	31.7	31.4

Soil magnesium, 0-15 cm, at harvest (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	.	4.3	6.0	5.5	6.8
2	.	3.4	.	.	5.1
3	6.1	2.9	.	4.4	4.0
4	5.5	5.0	2.9	3.7	4.3
5	3.6	3.3	2.1	4.4	1.8
6	.	4.9	4.0	4.1	4.4
7	.	6.5	4.3	6.8	6.0
8	6.4	9.2	6.7	7.9	5.2
9	4.3	4.1	4.3	4.8	4.3

Total soil cations, 0-15 cm, at harvest (me 100 g^{-1} soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	.	37.5	40.0	38.5	41.6
2	.	38.3	.	.	40.8
3	45.0	39.4	.	36.1	36.2
4	38.4	36.0	31.8	32.0	33.6
5	42.6	42.0	42.2	44.2	42.4
6	.	44.0	42.0	44.0	42.0
7	.	44.0	42.8	46.0	42.0
8	39.4	44.0	41.0	44.4	42.0
9	36.2	42.6	40.0	42.4	39.2

Soil organic matter 15-30 cm, at harvest (%).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	3.7	5.8	3.8	4.2	3.4
2	3.2	3.7	4.3	5.9	3.0
3	3.0	5.4	5.2	5.2	4.4
4	6.1	4.5	4.6	4.4	5.9
5	4.4	6.4	5.8	5.9	5.3
6	5.8	7.2	6.3	6.1	5.7
7	5.1	4.4	6.4	10.2	6.3
8	5.0	5.3	5.4	4.9	6.7
9	5.6	5.4	6.4	5.4	5.3

Soil phosphorus, 15-30 cm, at harvest (ppm).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	2.1	8.2	1.8	3.7	3.5
2	28.7	22.6	29.0	81.0	28.6
3	11.4	73.0	30.0	46.3	55.4
4	10.6	3.6	1.2	2.2	1.7
5	60.0	51.0	77.0	74.0	37.7
6	3.3	20.7	2.3	6.0	1.4
7	11.7	18.0	62.0	55.0	31.5
8	2.2	2.5	4.4	1.6	4.5
9	10.8	54.0	18.5	16.5	7.5

Soil potassium 15-30 cm, at harvest (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	1.03	1.88	0.78	1.34	1.09
2	0.91	0.92	0.75	1.69	0.91
3	0.75	0.95	0.80	0.86	1.15
4	0.98	0.78	0.52	1.02	1.17
5	0.94	1.88	1.29	1.67	1.52
6	0.90	1.20	1.30	1.51	1.14
7	0.89	1.08	1.28	1.43	1.28
8	1.00	1.18	0.75	1.13	1.62
9	1.19	1.49	1.29	1.30	1.20

Soil calcium 15-30 cm, at harvest (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	32.4	29.5	33.8	28.4	31.8
2	.	.	17.7	.	36.4
3	38.8	.	.	24.9	19.8
4	31.1	18.9	17.0	22.1	22.5
5	43.8	26.8	40.5	35.1	24.3
6	30.4	39.7	16.7	29.6	24.7
7	35.5	37.9	32.1	36.8	22.4
8	25.1	13.2	24.3	28.5	23.6
9	28.4	34.4	26.5	31.9	29.3

Soil magnesium 15-30 cm, at harvest (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	6.6	4.6	7.0	5.5	6.7
2	.	.	2.4	3.0	4.2
3	6.4	.	.	3.6	2.0
4	5.3	3.9	3.1	3.5	3.4
5	2.8	2.7	2.7	3.9	2.6
6	4.4	4.8	3.2	5.0	5.2
7	6.7	6.0	5.3	5.9	3.6
8	5.6	4.7	6.1	7.0	6.1
9	4.2	3.6	3.6	4.2	3.7

Total soil cations 15-30 cm, at harvest (me $100g^{-1}$ soil).

FARM	TAP	BARE	GLIR	CERO	ROWS
1	44.4	35.0	40.4	38.0	40.8
2	.	.	40.4	38.6	38.6
3	45.9	.	.	36.2	34.6
4	40.6	35.6	31.8	30.0	31.8
5	39.6	40.0	42.2	41.2	42.0
6	39.4	45.2	42.0	42.0	42.2
7	40.2	41.0	39.6	43.2	42.0
8	38.6	40.4	38.4	40.6	39.2
9	36.4	42.2	40.2	41.6	41.2

Nitrogen availability, as determined based on in-field nitrogen mineralization and microbial biomass analyses.
Nitrogen mineralization during the first sampling period (ppm)

FARM	ROWS	CERO	GLIR	BARE	TAP
1	2.82	4.81	2.70	3.63	.
2	3.68	10.47	5.10	4.72	2.78
3	4.62	2.70	4.58	6.48	1.76
4	2.71	4.72	4.63	4.01	1.14
5	5.72	7.44	5.68	7.41	1.05
6	3.33	7.15	.	6.72	3.49
7	.	8.83	1.92	3.85	3.13
8	5.81	6.53	.	4.41	3.59
9	4.19	4.73	3.29	4.04	2.52

Nitrogen mineralization during the second sampling period (ppm)

FARM	ROWS	CERO	GLIR	BARE	TAP
1	4.37	4.06	6.82	6.59	6.45
2	5.58	6.87	5.04	6.3	2.63
3	.	3.91	6.45	6.35	3.36
4	1.77	.	3.41	2.31	2.77
5	4.08	3.69	11.89	.	3.83
6	5.60	4.95	4.17	4.36	3.04
7	3.36	.	4.29	4.63	2.11
8	4.13	5.93	5.13	3.73	3.31
9	5.08	.	5.01	.	4.36

Microbial biomass nitrogen, at harvest (ppm).

FARM	ROWS	CERO	GLIR	BARE	TAP
1	62.97	47.17	22.91	74.14	59.14
2	44.78	85.06	48.98	99.70	37.78
3	48.11	51.02	58.45	39.40	19.88
4	80.41	41.11	39.40	59.74	75.95
5	51.02	93.00	74.27	38.08	57.07
6	132.42	84.10	105.13	115.28	116.56
7	100.08	117.26	77.19	89.13	93.00
8	.	130.20	145.86	112.58	110.44
9	94.55	85.25	93.26	116.72	83.90

Cumulative soil losses due to erosion during the growing season (kg ha^{-1}).

FARM	ROWS	CERO	GLIR	BARE	TAP
1	115.2	1.8	129.6	161.2	15.2
2	48.6	5.6	66.2	66.6	17.6
3	161.2	102.0	120.2	115.2	25.0
4	254.2	22.2	113.0	189.2	2.6
5	89.0	4.0	72.8	144.6	2.0
6	81.2	46.2	3.2	.	3.8
7	44.6	24.6	162.8	95.0	22.6
8	95.2	3.2	81.2	28.6	37.2
9	102.0	46.2	63.6	16.6	15.8

Nitrogen in the leaf tissue (%)

FARM	TAP	BARE	GLIR	CERO	ROWS
1	4.26	3.67	4.48	4.40	3.84
2	5.29	4.42	5.46	4.84	4.70
3	4.98	5.07	5.26	5.12	5.40
4	4.59	4.54	3.95	4.00	4.82
5	4.48	4.20	4.45	4.82	4.06
6	4.20	4.42	4.73	4.68	4.45
7	4.59	4.20	4.26	5.24	4.87
8	5.21	4.28	4.98	4.45	5.01
9	4.34	4.65	4.62	4.59	4.73

Phosphorus in the leaf tissue (%)

FARM	TAP	BARE	GLIR	CERO	ROWS
1	0.49	0.44	0.45	0.63	0.41
2	0.77	0.64	0.80	0.71	0.61
3	0.73	0.67	0.73	0.74	0.73
4	0.73	0.62	0.49	0.57	0.55
5	0.65	0.63	0.61	0.72	0.56
6	0.51	0.69	0.54	0.63	0.48
7	0.72	0.62	0.63	0.79	0.76
8	0.70	0.47	0.51	0.58	0.56
9	0.72	0.76	0.74	0.73	0.74

Nodule numbers

FARM	TAP	BARE	GLIR	CERO	ROWS
1	na	na	na	na	na
2	na	na	na	na	na
3	na	na	na	na	na
4	31	38	82	48	58
5	42	7	59	44	57
6	30	69	78	78	72
7	27	49	52	43	42
8	25	35	45	33	46
9	42	44	66	48	57

Penetrometer resistance (relative scale of 0-5)

FARM	TAP	BARE	GLIR	CERO	ROWS
1	0.73	0.95	0.64	0.47	0.65
2	0.65	0.85	0.85	0.75	0.85
3	1.20	1.40	1.10	1.10	1.25
4	1.10	2.25	1.50	1.40	3.20
5	1.10	3.00	1.20	1.40	2.90
6	1.60	2.50	1.85	0.95	1.60
7	0.70	1.80	1.30	0.70	1.60
8	0.85	1.25	1.20	0.70	0.55
9	0.20	1.25	0.40	0.35	0.75

Weight of weeds at harvest (tons ha^{-1})

FARM	ROWS	CERO	GLIR	BARE	TAP
1	1.20	0.59	1.27	1.94	2.18
2	1.23	1.06	1.48	1.48	1.51
3	0.76	0.37	0.60	0.39	0.79
4	1.44	1.94	1.67	2.27	0.79
5	2.50	3.89	4.68	1.20	1.02
6	2.27	1.76	2.04	1.20	1.39
7	2.96	2.92	1.94	3.56	4.17
8	4.77	3.15	4.17	3.98	7.87
9	1.34	0.97	1.76	1.39	1.39

Yields (kg ha^{-1})

FARM	TAP	BARE	GLIR	CERO	ROWS
1	469.9	624.1	603.5	723.6	420.0
2	365.6	787.7	897.3	559.7	820.4
3	705.0	1091.0	794.0	805.1	1142.5
4	352.2	916.9	892.8	651.9	821.7
5	400.2	837.8	826.2	639.6	924.8
6	594.8	1028.1	810.4	769.6	723.4
7	199.3	712.5	748.6	621.8	1124.4
8	423.3	685.4	809.4	537.3	785.3
9	652.9	1209.4	1134.4	787.8	981.3

Average values across treatments.

FARM	YIELDS	FALLOW	WEEDS	EROSION	LEAF-P	SOIL P	OM
1	568.2	0.75	1.436	73.8	0.54	7.84	4.42
2	686.1	2.0	1.352	41.0	0.51	93.5	5.94
3	907.5	3.0	0.582	104.8	0.5	63.0	5.54
4	727.1	1.5	1.622	116.2	0.59	5.36	5.48
5	725.7	1.0	2.658	62.4	0.48	104.2	6.76
6	785.3	4.5	1.732	33.8	0.6	9.2	6.34
7	681.3	1.5	3.110	70.0	0.51	45.1	6.06
8	648.1	1.0	4.788	49.0	0.57	5.96	6.26
9	953.2	4.0	1.334	48.8	0.53	25.8	5.1

Aggregate stability at harvest (Grams of soil remaining on sieve of size indicated after sieving 25 g soil. TOT = total weight of soil recovered on sieves. ADJWT = oven dry weight of the 25g of air dried soil)

FARM	TREAT	10	20	40	60	80	>80	TOT	ADJWT
1	B	13.43	3.67	2.67	1.07	0.49	2.02	21.33	23.35
1	C	18.25	1.65	1.26	0.54	0.19	1.31	21.89	23.2
1	F	16.52	2.21	1.72	0.9	0.39	1.31	21.74	23.05
1	G	5.88	3.93	5.05	2.82	0.51	4.94	18.19	23.13
1	T	10.77	3.48	3.13	1.56	1.04	2.82	19.98	22.80
1	W	7.72	3.99	4.75	2.27	0.24	4.11	18.97	23.08
2	B	14.75	2.29	2.82	1.35	0.7	2.54	21.91	24.45
2	C	12.91	3.16	3.12	1.53	0.31	3.35	21.03	24.38
2	F	14.09	3.5	2.67	0.98	0.02	1.72	21.26	22.98
2	G	14.03	3.03	2.76	0.65	0.25	2.58	20.72	23.30
2	T	12.44	3.89	3.53	1.2	0.35	2.09	21.41	23.50
2	W	14.87	3.07	2.47	1.05	0.08	1.79	21.54	23.33
3	B	13.06	3.62	3.33	1.39	0.07	2.03	21.47	23.50
3	C	17.49	1.0	1.52	1.0	.	3.22	21.01	24.23
3	G	13.41	2.55	2.94	1.6	0.84	2.96	21.34	24.30
3	T	14.4	2.59	2.59	1.24	0.33	2.73	21.15	23.88
3	W	17.7	2.12	1.49	0.66	0.08	1.33	22.05	23.38
4	B	9.84	5.02	4.1	1.57	0.32	2.53	20.85	23.38
4	C	8.37	6.26	4.68	1.46	0.05	2.83	20.82	23.65
4	F	11.32	4.8	3.45	1.29	0.2	3.07	21.06	24.13
4	G	10.59	4.37	4.21	1.63	0.29	2.41	21.09	23.5
4	T	10.08	4.8	4.05	1.53	0.56	2.36	21.02	23.38
4	W	6.68	6.16	5.78	2.01	0.26	3.34	20.89	24.23
5	B	7.71	6.12	5.41	1.62	0.37	2.27	21.23	23.5
5	C	9.79	6.58	4.55	1.22	0.25	1.01	22.39	23.4
5	G	8.54	5.33	5.12	1.78	0.47	2.14	21.24	23.38
5	T	13.96	4.29	3.05	0.92	0.08	0.7	22.3	23.00
5	W	8.24	5.96	4.86	1.65	0.27	2.35	20.98	23.33
6	B	13.13	4.58	2.83	0.76	0.18	1.47	21.48	22.95
6	C	.	.	.	.	.	.	.	.
6	F	11.62	5.96	3.67	0.76	0.02	1.0	22.03	23.03
6	G	15.48	4.18	2.09	0.52	0.02	0.89	22.29	23.18
6	T	18.02	2.62	1.33	0.4	0.02	0.69	22.39	23.08
6	W	12.87	5.25	3.1	0.8	.	1.93	22.02	23.95
7	B	17.47	2.29	1.47	0.51	0.14	1.02	21.88	22.90
7	C	14.6	3.26	1.48	0.9	0.46	2.35	20.7	23.05
7	F	17.17	2.73	1.66	0.57	0.21	1.74	22.34	24.08
7	G	14.66	3.25	2.47	0.87	.	2.7	21.25	23.95
7	T	20.35	0.82	0.89	0.27	0.01	1.71	22.34	24.05
7	W	14.96	3.96	2.26	0.84	0.22	1.74	22.24	23.98
8	B	6.3	7.48	5.45	1.59	0.22	1.69	21.04	22.73
8	C	7.84	6.42	4.97	1.63	0.11	2.82	20.97	18.15
8	F	20.35	1.4	0.81	0.21	0.01	0.25	22.78	22.53
8	G	12.85	4.32	3.35	1.24	0.32	8.38	22.08	13.70
8	T	12.07	4.59	3.58	1.4	0.35	2.04	21.99	24.03
8	W	12.6	5.0	3.78	0.97	0.02	0.63	22.37	23.00
9	B	13.99	3.63	2.8	0.94	0.1	1.77	21.46	23.23
9	C	13.03	3.13	3.21	1.39	0.23	2.14	20.99	23.13
9	F	17.35	2.95	1.57	0.52	0.01	0.55	22.4	22.95
9	G	14.75	3.92	2.44	0.76	0.07	1.31	21.94	23.25
9	T	10.5	6.52	4.11	1.11	0.11	1.85	22.35	24.20
9	W	12.08	5.6	3.72	1.01	0.26	1.33	22.67	24.00

APPENDIX E
DATA FOR EXPERIMENTS DESCRIBED IN CHAPTER 5

Farms are described in Chapter 5. Preparation methods: Cero=labranza cero, Burn= residues burned, Clear=residues manually cleared. Phosphorus subtreatment (PHO): 1 = with P fertilizer, 2 = without P fertilizer. Rhizobia inoculation sub-subtreatment (RHIZ): 1 = with rhizobia inoculum, 2 = without rhizobia inculum).

I. Soil organic matter (%) at planting and harvest (OM-p and OM-h) and soil pH at planting and harvest (pH-p and pH-h).

Treatment				Variables			
FARM	REP	PREP	PHO	OM-p	OM-h	pH-p	pH-h
I	1	Cero	1	4.62	5.12	6.2	5.8
I	1	Cero	2	4.35	4.17	6.2	5.9
I	1	Clear	1	5.17	4.85	.	5.8
I	1	Clear	2	4.90	4.31	5.8	5.9
I	1	Burn	1	4.22	4.17	6.1	5.6
I	1	Burn	2	4.76	4.44	6.2	5.7
I	2	Cero	1	3.54	3.77	6.3	6.1
I	2	Cero	2	3.67	4.85	6.2	5.8
I	2	Clear	1	3.94	3.37	5.8	5.7
I	2	Clear	2	3.94	3.10	6.1	5.7
I	2	Burn	1	4.62	4.17	6.1	6.0
I	2	Burn	2	3.94	3.77	6.4	6.0
I	3	Cero	1	3.54	3.50	6.4	5.9
I	3	Cero	2	4.08	4.17	6.1	6.0
I	3	Clear	1	4.35	5.12	6.1	5.7
I	3	Clear	2	4.35	3.90	6.2	5.9
I	3	Burn	1	3.81	4.71	6.4	5.8
I	3	Burn	2	3.81	4.58	6.3	6.0
II	1	Cero	1	3.94	5.12	.	5.9
II	1	Cero	2	4.08	4.31	5.8	5.7
II	1	Clear	1	4.22	5.52	6.0	5.9
II	1	Clear	2	4.90	4.85	6.0	5.8
II	1	Burn	1	4.35	5.52	6.0	6.6
II	1	Burn	2	4.76	5.92	7.3	6.6

II. Soil organic matter (%) at planting and harvest (OM-p and OM-h) and soil pH at planting and harvest (pH-p and pH-h) (continued).

FARM	REP	PREP	PHO	OM-p	OM-h	pH-p	pH-h
II	2	Cero	1	5.58	5.25	6.2	6.1
II	2	Cero	2	4.49	5.25	6.1	5.7
II	2	Clear	1	5.03	5.12	6.0	5.9
II	2	Clear	2	5.58	5.79	6.2	5.8
II	2	Burn	1	5.85	6.33	6.0	5.8
II	2	Burn	2	5.30	5.25	5.9	6.1
II	3	Cero	1	5.17	5.52	6.4	6.1
II	3	Cero	2	4.76	5.39	6.3	6.2
II	3	Clear	1	6.26	6.19	6.6	6.7
II	3	Clear	2	6.12	5.79	6.3	6.1
II	3	Burn	1	4.35	6.73	6.6	6.7
II	3	Burn	2	4.62	4.85	6.4	6.2

III. Pentetrometer resistance (PENT), aggregate stability (gm soil in sieve of mesh size listed remaining after sieving 25 g soil), and bulk density (g $cm^{-3)}$ (BULK).

FARM	TRT	REP	PENT	10	20	40	60	80	BULK
I	Cero	1	1.3	10.41	4.03	3.91	1.93	2.04	0.92
I	Clear	1	3.7	12.18	3.33	3.1	1.46	2.26	0.88
I	Burn	1	2.07	9.23	4.36	3.75	1.83	2.96	0.98
I	Cero	2	1.1	13.81	3.47	2.47	1.28	1.92	1.01
I	Clear	2	3.06	13.15	2.79	2.65	1.52	2.4	1.03
I	Burn	2	1.5	9.03	4.67	4.07	2.07	2.65	1.06
I	Cero	3	1.5	11.93	3.79	3.29	1.5	2.2	0.95
I	Clear	3	1.76	9.56	4.22	4.13	1.81	2.67	0.91
I	Burn	3	2.1	11.18	3.64	3.66	1.59	2.47	0.84
II	Cero	1	2.3	15.75	2.71	1.87	0.91	1.46	1.09
II	Clear	1	2.9	13.69	3.42	2.46	1.17	1.98	1.0
II	Burn	1	2.65	14.32	3.39	2.32	1.01	0.22	1.03
II	Cero	2	1.59	12.18	4.22	3.42	1.4	1.52	1.03
II	Clear	2	3.99	15.68	2.72	2.18	1.06	1.44	1.01
II	Burn	2	2.9	12.9	3.31	2.9	1.44	2.08	1.01
II	Cero	3	1.85	14.8	3.64	2.49	0.97	1.15	1.03
II	Clear	3	2.49	13.32	4.67	2.6	1.02	1.3	0.95
II	Burn	3	1.97	14.51	4.2	2.28	0.87	1.14	0.99

IV. Nutrients in ash samples (kg ha^{-1}) (Nash=nitrogen in ash, Pash=phosphorus in ash, Kash=potassium in ash).

FINCA	TREAT	REP	Nash	Pash	Kash
I	Burn	1	19.2	7.3	22.6
I	Burn	2	24.1	8.2	29.8
I	Burn	3	19.3	4.5	28.4
II	Burn	1	6.6	4	15.8
II	Burn	2	6.3	1.4	6.3
II	Burn	3	1.4	0.7	2.2

V. Weight (kg ha^{-1}) (RES-wt) and nutrients (kg ha^{-1}) in mulch residues (Nres=nitrogen in residues, Pres=phosphorus in residues, Kres=potassium in residues).

FARM	TREAT	REP	RES-wt	Nres	Pres	Kres
I	Cero	1	15920	89.2	33.4	156
I	Clear	1	13600	57.1	34.0	134.6
I	Burn	1	14040	78.6	9.8	67.4
I	Cero	2	18240	91.2	36.5	133.2
I	Clear	2	20720	128.5	18.6	55.9
I	Burn	2	16240	86.1	14.6	103.9
I	Cero	3	17560	128.2	31.6	133.5
I	Clear	3	19240	82.7	30.8	138.5
I	Burn	3	22160	124.1	35.5	155.1
II	Cero	1	9760	43.9	17.6	75.2
II	Clear	1	10200	68.3	14.3	87.7
II	Burn	1	3960	23.4	6.3	24.6
II	Cero	2	9040	47.9	9.0	34.4
II	Clear	2	8920	37.5	8.0	33.9
II	Burn	2	11120	58.9	11.1	51.2
II	Cero	3	5000	26.5	7.5	35.0
II	Clear	3	6960	48.7	9.0	38.3
II	Burn	3	7080	39.6	9.2	54.5

V. Phosphorus data during five sampling periods (ppm). Sampling times are described in Chapter 5.

FARM	TREAT	REP	PHO	1st	2nd	3rd	4th	harvest
I	Cero	1	1	4.31	3.69	8.62	6.99	4.55
I	Cero	1	2	2	3.23	6.31	4.23	4.07
I	Clear	1	1	4.15	5.54	7.23	3.9	4.88
I	Clear	1	2	4.92	3.08	4.46	3.74	3.9
I	Burn	1	1	6	6.62	8.77	5.2	6.34
I	Burn	1	2	8.31	7.69	9.38	5.04	6.02
I	Cero	2	1	18.15	3.54	20.15	7.8	4.39
I	Cero	2	2	7.38	3.08	5.69	5.2	5.04
I	Clear	2	1	6.92	2.46	4.77	3.74	.
I	Clear	2	2	2.77	5.23	4.77	5.53	5.2
I	Burn	2	1	5.69	8.15	6.31	5.53	5.37
I	Burn	2	2	7.23	7.38	9.23	6.34	4.55
I	Cero	3	1	1.69	1.69	3.54	3.74	7.48
I	Cero	3	2	2.15	2.46	5.38	3.41	2.93
I	Clear	3	1	2.31	2.77	5.85	7.32	6.5
I	Clear	3	2	4.31	3.08	5.23	3.74	3.74
I	Burn	3	1	1.69	3.69	4.77	6.83	4.39
I	Burn	3	2	3.54	2.62	4.46	5.85	4.07
II	Cero	1	1	9.38	.	18.31	18.86	8.46
II	Cero	1	2	9.85	13.38	9.38	7.64	9.43
II	Clear	1	1	10.62	10.46	15.38	13.17	12.68
II	Clear	1	2	6.92	10	16.15	7.32	8.13
II	Burn	1	1	31.85	17.23	28.92	11.71	17.72
II	Burn	1	2	24.62	34	21.85	18.05	18.37

V. continued.

FARM	TREAT	REP	PHO	1st	2nd	3rd	4th	harvest
II	Cero	2	1	13.23	23.38	29.85	15.28	19.84
II	Cero	2	2	14	25.85	21.08	18.21	15.61
II	Clear	2	1	22.15	20.15	25.54	13.5	26.67
II	Clear	2	2	36.46	31.38	34	15.45	30.73
II	Burn	2	1	19.23	18.15	21.85	13.17	30.08
II	Burn	2	2	19.23	14.15	21.38	15.12	25.2
II	Cero	3	1	11.85	10	17.85	10.41	17.89
II	Cero	3	2	16.46	10	20.92	15.61	11.38
II	Clear	3	1	38.77	29.08	29.85	17.07	28.94
II	Clear	3	2	12.77	15.69	22.92	10.24	11.22
II	Burn	3	1	20.77	25.08	36.92	22.93	34.47
II	Burn	3	2	21.08	31.08	25.69	24.88	15.61

VI. Nitrogen mineralization (ppm NO_3-) during three sampling periods. (See Chapter 5 for sampling times)

FARM	TREAT	REP	PHO	1st	2nd	Harvest	Total
I	Cero	1	1	5.7	1.8	18.9	26.4
I	Cero	1	2	2.6	2.0	8.7	13.3
I	Clear	1	1	3.5	4.8	13.0	21.3
I	Clear	1	2	2.9	6.2	13.3	22.4
I	Burn	1	1	1.3	4.2	7.8	13.3
I	Burn	1	2	4.9	12.7	10.5	28.1
I	Cero	2	1	3.8	9.5	16.8	30.1
I	Cero	2	2	0	11.0	9.1	20.1
I	Clear	2	1	5.4	7.2	6.6	19.2
I	Clear	2	2	5.6	4.7	9.4	19.7
I	Burn	2	1	5.2	9.5	5.8	20.5
I	Burn	2	2	3	9.6	10.6	23.2
I	Cero	3	1	0	0.7	10.6	11.3
I	Cero	3	2	0	0	9.3	9.3
I	Clear	3	1	0.4	4.7	18.2	23.3
I	Clear	3	2	3.9	4.0	16.5	24.4
I	Burn	3	1	0	0	4.4	4.4
I	Burn	3	2	0	1.5	8.0	9.5
II	Cero	1	1	12.7	9.0	35.4	57.1
II	Cero	1	2	14.6	9.3	33.6	57.5
II	Clear	1	1	26.8	26.4	22.6	75.8
II	Clear	1	2	0	3.3	33.5	36.8
II	Burn	1	1	30.6	12.5	23.7	66.8
II	Burn	1	2	13.2	2.5	40.7	56.4
II	Cero	2	1	16.8	9.5	30.7	57.0
II	Cero	2	2	26.0	16.5	33.4	75.9
II	Clear	2	1	31.8	3.7	26.8	62.3
II	Clear	2	2	41.5	14.3	29.4	85.2
II	Burn	2	1	29.1	12.2	28.3	69.6
II	Burn	2	2	31.8	9.5	23.9	65.2
II	Cero	3	1	11.6	11.0	25.6	48.2
II	Cero	3	2	15.5	16.9	29.3	61.7
II	Clear	3	1	22.4	13.0	22.0	57.4
II	Clear	3	2	21.3	11.1	20.7	53.1
II	Burn	3	1	23.4	13.2	31.8	68.4
II	Burn	3	2	10.9	12.1	25.8	48.8

VII. Microbial biomass (ppm ninhydrin reactive nitrogen) at three sampling periods. See Chapter 5 for sampling times.

FARM	TREAT	REP	PHO	Planting	10 DAP	24 DAP
I	Cero	1	1	105.72	116.41	140.64
I	Cero	1	2	100.79	115.07	132.27
I	Clear	1	1	135.75	93.98	118.63
I	Clear	1	2	115.95	76.14	114.69
I	Burn	1	1	143.06	79.54	111.71
I	Burn	1	2	142.01	116.18	121.32
I	Cero	2	1	102.14	127.74	121.46
I	Cero	2	2	100.35	107.91	119.87
I	Clear	2	1	118.22	71.57	107.77
I	Clear	2	2	112.61	83.92	92.55
I	Burn	2	1	116.63	94.69	112.38
I	Burn	2	2	107.91	71.42	103.02
I	Cero	3	1	115.04	88.56	105.64
I	Cero	3	2	107.01	80.66	118.38
I	Clear	3	1	116.2	78.53	114.21
I	Clear	3	2	126.07	71.50	105.90
I	Burn	3	1	145.36	69.31	109.53
I	Burn	3	2	112.52	55.04	97.96
II	Cero	1	1	47.6	90.82	116.38
II	Cero	1	2	55.04	113.28	110.79
II	Clear	1	1	104.78	113.28	106.72
II	Clear	1	2	97.08	109.70	91.78
II	Burn	1	1	134.22	87.30	93.05
II	Burn	1	2	105.15	93.03	122.82
II	Cero	2	1	118.56	111.66	118.31
II	Cero	2	2	106.25	108.26	108.77
II	Clear	2	1	66.13	105.01	93.13
II	Clear	2	2	80.71	153.05	100.87
II	Burn	2	1	59.77	83.11	109.37
II	Burn	2	2	48.74	105.37	106.41
II	Cero	3	1	34.37	70.60	109.37
II	Cero	3	2	51.56	84.23	117.02
II	Clear	3	1	83.3	117.28	118.52
II	Clear	3	2	95.72	94.20	117.01
II	Burn	3	1	66.98	111.49	117.43
II	Burn	3	2	89.03	74.40	117.64

VIII. Nitrogen and phosphorus in plant tissue at midseason (%).

FARM	TREAT	REP	P	R	N	P
I	Clear	3	1	1	3.69	0.287
I	Clear	1	1	1	3.80	0.222
I	Clear	2	1	1	2.78	0.220
I	Clear	2	1	2	2.78	0.233
I	Clear	1	1	2	3.50	0.236
I	Clear	3	1	2	3.92	0.303
I	Clear	3	2	1	.	0.202
I	Clear	1	2	1	4.10	0.212
I	Clear	2	2	1	3.97	0.201
I	Clear	2	2	2	4.20	0.180
I	Clear	1	2	2	4.30	0.210
I	Clear	3	2	2	.	0.214
I	Cero	2	1	1	3.40	0.310
I	Cero	1	1	1	4.00	0.312
I	Cero	3	1	1	3.97	0.391
I	Cero	3	1	2	3.41	0.423
I	Cero	2	1	2	.	0.322
I	Cero	1	1	2	4.95	0.329
I	Cero	2	2	1	3.75	0.369
I	Cero	1	2	1	4.90	0.346
I	Cero	3	2	1	4.26	0.333
I	Cero	1	2	2	5.20	0.328
I	Cero	3	2	2	4.31	0.346
I	Cero	2	2	2	3.35	0.343
I	Burn	2	1	1	3.12	0.239
I	Burn	3	1	1	3.97	0.323
I	Burn	1	1	1	3.60	0.322
I	Burn	3	1	2	3.40	0.272
I	Burn	1	1	2	3.80	0.308
I	Burn	2	1	2	3.40	0.253
I	Burn	2	2	1	3.46	0.273
I	Burn	1	2	1	4.50	0.338
I	Burn	3	2	1	4.60	0.290
I	Burn	1	2	2	3.60	0.309
I	Burn	2	2	2	3.46	0.297
I	Burn	3	2	2	4.26	0.316
II	Clear	2	1	1	4.55	0.402
II	Clear	1	1	1	4.30	0.384
II	Clear	3	1	1	4.70	0.434
II	Clear	3	1	2	5.30	0.433
II	Clear	1	1	2	4.95	0.340
II	Clear	2	1	2	5.45	0.405
II	Clear	2	2	1	5.40	0.451
II	Clear	1	2	1	4.60	0.321
II	Clear	3	2	1	5.55	0.395
II	Clear	1	2	2	4.55	0.313
II	Clear	3	2	2	5.35	0.424
II	Clear	2	2	2	5.50	0.404

VIII. continued.

FARM	TREAT	REP	P	R	N	P
II	Cero	1	1	1	4.60	0.363
II	Cero	2	1	1	4.54	0.424
II	Cero	3	1	1	5.35	0.452
II	Cero	3	1	2	5.55	0.455
II	Cero	2	1	2	4.50	0.416
II	Cero	1	1	2	4.85	0.369
II	Cero	2	2	1	4.65	0.422
II	Cero	1	2	1	4.85	0.387
II	Cero	3	2	1	5.45	0.400
II	Cero	1	2	2	5.10	0.373
II	Cero	3	2	2	5.25	0.475
II	Cero	2	2	2	4.65	0.453
II	Burn	1	1	1	4.95	0.437
II	Burn	3	1	1	5.50	0.480
II	Burn	2	1	1	5.05	0.451
II	Burn	3	1	2	4.90	0.489
II	Burn	2	1	2	5.25	0.460
II	Burn	1	1	2	3.80	0.431
II	Burn	1	2	1	4.20	0.415
II	Burn	2	2	1	5.40	0.422
II	Burn	3	2	1	4.60	0.434
II	Burn	2	2	2	5.45	0.436
II	Burn	1	2	2	4.56	0.420
II	Burn	3	2	2	5.05	0.502

IX. Nodulation (NODS) (numbers plant^{-1}), plant biomass (grams plant^{-1}) above ground (AG), root (ROOT), and total plant (TOTAL) at midseason.

FARM	TREAT	REP	PHO	RHI	NODS	AG	ROOT	TOTAL
I	Clear	1	1	1	7.71	1.27	0.39	1.65
I	Clear	1	1	2	5.84	1.7	0.51	2.2
I	Clear	1	2	1	2.4	0.77	0.23	1.0
I	Clear	1	2	2	1.67	0.82	0.24	1.05
I	Clear	2	1	1	14.07	1.41	0.48	1.89
I	Clear	2	1	2	6.67	1.55	0.42	1.97
I	Clear	2	2	1	3.13	0.83	0.29	1.12
I	Clear	2	2	2	3.23	0.52	0.2	0.71
I	Clear	3	1	1	10.53	1.15	0.38	1.53
I	Clear	3	1	2	3.75	1.1	0.34	1.44
I	Clear	3	2	1	5.11	0.63	0.21	0.83
I	Clear	3	2	2	4.57	0.52	0.18	0.7
I	Cero	1	1	1	6.88	2.4	0.54	2.93
I	Cero	1	1	2	6.88	2.19	0.52	2.71
I	Cero	1	2	1	1.78	1.73	0.42	2.15
I	Cero	1	2	2	4.69	1.36	0.36	1.72
I	Cero	2	1	1	19.28	2.84	0.62	3.46
I	Cero	2	1	2	22.09	2.28	0.52	2.8
I	Cero	2	2	1	10.21	1.45	0.41	1.85
I	Cero	2	2	2	7.61	1.48	0.35	1.82
I	Cero	3	1	1	25.84	1.75	0.45	2.19
I	Cero	3	1	2	24.75	1.75	0.41	2.16

IX. continued.

FARM	TREAT	REP	PHO	RHI	NODS	AG	ROOT	TOTAL
I	Cero	3	2	1	17.4	1.22	0.3	1.52
I	Cero	3	2	2	15.32	1.19	0.25	1.44
I	Burn	1	1	1	20.84	1.82	0.42	2.23
I	Burn	1	1	2	12.92	2.37	0.31	2.68
I	Burn	1	2	1	7.61	0.82	0.25	1.06
I	Burn	1	2	2	13.23	1.53	0.37	1.9
I	Burn	2	1	1	14.07	3.23	0.63	3.86
I	Burn	2	1	2	4.69	2.88	0.59	3.47
I	Burn	2	2	1	4.07	2.08	0.43	2.5
I	Burn	2	2	2	11.57	2.68	0.52	3.2
I	Burn	3	1	1	10.63	1.59	0.45	2.04
I	Burn	3	1	2	13.75	1.52	0.42	1.94
I	Burn	3	2	1	11.88	1.15	0.3	1.44
I	Burn	3	2	2	9.48	1.28	0.34	1.62
II	Clear	1	1	1	22.71	2.82	0.56	3.38
II	Clear	1	1	2	16.98	2.8	0.49	3.28
II	Clear	1	2	1	8.88	3.28	0.55	3.83
II	Clear	1	2	2	17.34	3.08	0.55	3.63
II	Clear	2	1	1	24.59	2.85	0.58	3.43
II	Clear	2	1	2	23.96	2.94	0.64	3.57
II	Clear	2	2	1	12.5	2.21	0.45	2.66
II	Clear	2	2	2	12.19	2.58	0.61	3.19
II	Clear	3	1	1	16.78	2.14	0.44	2.58
II	Clear	3	1	2	8.92	1.53	0.33	1.85
II	Clear	3	2	1	18.65	1.75	0.44	2.19
II	Clear	3	2	2	20.73	1.53	0.34	1.87
II	Cero	1	1	1	27.71	2.93	0.59	3.51
II	Cero	1	1	2	21.98	2.8	0.51	3.3
II	Cero	1	2	1	16.46	2.57	0.49	3.05
II	Cero	1	2	2	13.17	2.51	0.52	3.03
II	Cero	2	1	1	21.78	3.47	0.74	4.21
II	Cero	2	1	2	22.09	2.91	0.6	3.5
II	Cero	2	2	1	9.38	2.89	0.65	3.54
II	Cero	2	2	2	9.59	2.72	0.56	3.28
II	Cero	3	1	1	16.57	2.31	0.45	2.75
II	Cero	3	1	2	17.19	2.33	0.47	2.8
II	Cero	3	2	1	14.4	2.45	0.59	3.04
II	Cero	3	2	2	10.38	1.92	0.21	2.13
II	Burn	1	1	1	35.23	3.06	0.53	3.59
II	Burn	1	1	2	16.17	2.9	0.25	3.15
II	Burn	1	2	1	13.96	2.69	0.5	3.18
II	Burn	1	2	2	18.75	2.88	0.52	3.4
II	Burn	2	1	1	35.53	2.64	0.66	3.3
II	Burn	2	1	2	15.15	2.71	0.6	3.31
II	Burn	2	2	1	15.63	2.29	0.41	2.69
II	Burn	2	2	2	13.54	2.27	0.38	2.65
II	Burn	3	1	1	40.00	1.93	0.51	2.44
II	Burn	3	1	2	18.75	1.92	0.43	2.35
II	Burn	3	2	1	15.00	2.12	0.36	2.48
II	Burn	3	2	2	8.65	1.71	0.38	2.09

X. Percent uninfected plants (CLEAN), Yields (YIELD) (kg ha^{-1}), weight of unsaleable seeds (kg ha^{-1}) (BAD), and saleable yields (kg ha^{-1}) (SALES) at harvest.

FARM	TREAT	REP	PHO	RHIZ	CLEAN	YIELD	BAD	SALES
I	Cero	1	1	1	88.1	1702	102	1600
I	Cero	1	1	2	14	1964	137	1827
I	Cero	1	2	1	99	1427	29	1398
I	Cero	1	2	2	83.5	1604	0	1604
I	Clear	1	1	1	15.3	1120	45	1075
I	Clear	1	1	2	35.1	1360	122	1238
I	Clear	1	2	1	48.5	503	10	493
I	Clear	1	2	2	32.7	690	124	566
I	Burn	1	1	1	11.5	1840	110	1730
I	Burn	1	1	2	11	1938	39	1899
I	Burn	1	2	1	61.2	1487	119	1368
I	Burn	1	2	2	54.4	1990	119	1871
I	Cero	2	1	1	76.3	2240	0	2240
I	Cero	2	1	2	69.9	2310	116	2194
I	Cero	2	2	1	87.2	1538	292	1246
I	Cero	2	2	2	80.5	1874	56	1818
I	Clear	2	1	1	84.5	1328	0	1328
I	Clear	2	1	2	75.5	1300	65	1235
I	Clear	2	2	1	76.7	940	38	902
I	Clear	2	2	2	81.8	782	47	735
I	Burn	2	1	1	22.7	1804	90	1714
I	Burn	2	1	2	31.5	2590	26	2564
I	Burn	2	2	1	10.3	1724	0	1724
I	Burn	2	2	2	62	2108	105	2003
I	Cero	3	1	1	90.3	1757	70	1687
I	Cero	3	1	2	84.2	1727	35	1692
I	Cero	3	2	1	80.2	1350	41	1309
I	Cero	3	2	2	81.4	1103	55	1048
I	Clear	3	1	1	76.9	1328	0	1328
I	Clear	3	1	2	75.8	1264	63	1201
I	Clear	3	2	1	89.7	684	7	677
I	Clear	3	2	2	88.9	776	31	745
I	Burn	3	1	1	86.7	2017	20	1997
I	Burn	3	1	2	87.3	1853	19	1834
I	Burn	3	2	1	92.6	1813	0	1813
I	Burn	3	2	2	92.3	1810	36	1774
II	Cero	1	1	1	21.1	1575	142	1433
II	Cero	1	1	2	56	2149	43	2106
II	Cero	1	2	1	27.9	2076	311	1765
II	Cero	1	2	2	71.7	1800	18	1782
II	Clear	1	1	1	49.3	1705	290	1415
II	Clear	1	1	2	32.8	1684	168	1516
II	Clear	1	2	1	40	1287	154	1133
II	Clear	1	2	2	60.6	2000	140	1860
II	Burn	1	1	1	17.9	1996	160	1836
II	Burn	1	1	2	44	2662	27	2635
II	Burn	1	2	1	45.8	2647	159	2488
II	Burn	1	2	2	42.6	2473	99	2374

X. continued.

FARM	TREAT	REP	PHO	RHIZ	CLEAN	YIELD	BAD	SALES
II	Cero	2	1	1	20	1869	523	1346
II	Cero	2	1	2	36.9	1625	260	1365
II	Cero	2	2	1	54.2	1883	377	1506
II	Cero	2	2	2	47.8	2083	375	1708
II	Clear	2	1	1	26.1	1444	621	823
II	Clear	2	1	2	27	1556	607	949
II	Clear	2	2	1	20.3	1293	491	802
II	Clear	2	2	2	53.8	1860	521	1339
II	Burn	2	1	1	30.6	1473	486	987
II	Burn	2	1	2	21.9	1593	701	892
II	Burn	2	2	1	49.5	1265	316	949
II	Burn	2	2	2	28.2	1447	535	912
II	Cero	3	1	1	18.6	1604	96	1508
II	Cero	3	1	2	33.3	1800	108	1692
II	Cero	3	2	1	34.9	1538	200	1338
II	Cero	3	2	2	55.4	1727	35	1692
II	Clear	3	1	1	25.5	1720	138	1582
II	Clear	3	1	2	16.7	1447	87	1360
II	Clear	3	2	1	31.3	1687	17	1670
II	Clear	3	2	2	55.6	1040	52	988
II	Burn	3	1	1	34.1	2160	194	1966
II	Burn	3	1	2	11.6	1705	358	1347
II	Burn	3	2	1	50	2120	127	1993
II	Burn	3	2	2	65.5	2080	125	1955

BIOGRAPHIC SKETCH

Barbara Carol Bellows was born in Westfield, Massachusetts on July 23, 1954. She graduated from Mt. Horeb High School, Mt. Horeb, Wisconsin in 1972. In 1976, she received a Bachelor of Arts degree in South Asian studies from the University of Wisconsin-Madison, and in 1981, she received a Master of Science degree in agronomy and soil science from the University of Hawaii-Manoa.

From 1981 to 1983, Barbara worked as an anaerobic microbiologist at the University of Wisconsin. In 1983, she joined the U.S. Peace Corps where she served as an agricultural extension agent in the Philippines for three years. Following completion of her Peace Corps service, she worked for two years as an agricultural extension liaison officer and soil science instructor with Xavier University in Cagayen de Oro, Philippines.

Barbara began her doctoral studies at the University of Florida in May 1988. Her dissertation research was conducted in Costa Rica with assistance from CIAT and CATIE.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. David H. Hubbell, Chair
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. Brian L. McNeal
Professor of Soil Science

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Dr. Peter E. Hildebrand
Professor of Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. Kenneth L. Buhr
Assistant Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May, 1992

Jack L. Fry
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